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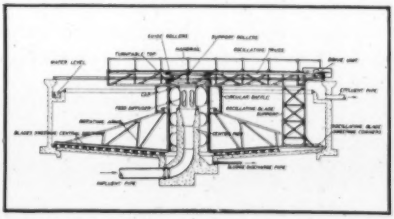

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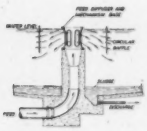

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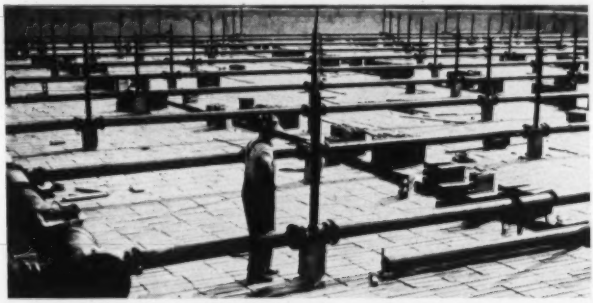

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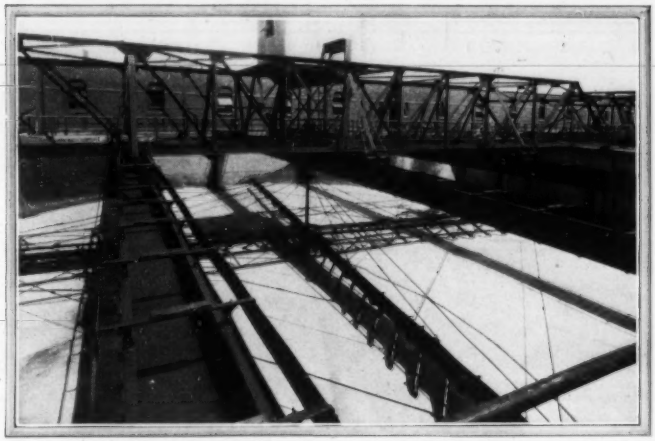

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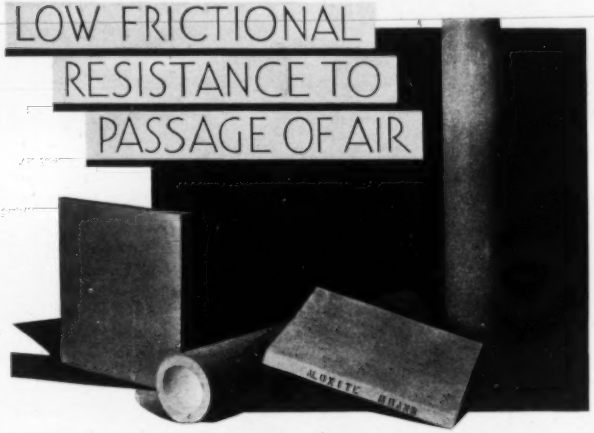

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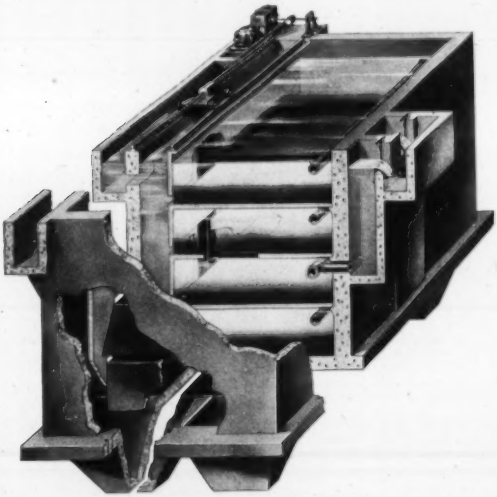

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Sewage Research

The Interchange of Heat During Sludge Digestion

By C. E. Keefer and Herman Kratz

Principal Assistant Engineer and Junior Chemist, Bureau of Sewers, Baltimore, Md.

During the past few years there has been considerable discussion in the literature concerning the production of heat during sludge digestion. The first record that has been found of studies made to ascertain whether sludge gives off or absorbs heat during digestion is that of the work of Popoff[1] in 1875. He observed that the temperature of decomposing sludge in a 1500-cc. flask, which was kept in a cellar at a temperature of 6° to 7° C., was as much as 0.9° to 1.0° C. higher than the surrounding atmosphere. This problem has also been investigated in a different way by Prüss,[2] who made a series of studies of the heat added and lost from a sludge tank with a capacity of 53,000 cu. ft., at Essen-Nord, Germany. He calculated the heat loss from the tank, which was always considerably in excess of the heat introduced through incoming heated sludge. He concluded that this difference in heat was that generated by the decomposing material, and estimated it to vary from 11.3 to 16.9 B. t. u. per cu. ft. of sludge per day.

Bach[3] made an extensive study of the heat content of the organic matter in raw and digested sludge and the heat value of the gas produced. As a result of these studies he concluded that 4 per cent of the heat content of fresh sludge is available for self-heating. Bach further stated: "In the digestion of sludge endothermic and exothermic conditions are present. The exothermic conditions are in the majority."

Another group of investigations was conducted by Sierp,[4] who also concluded that heat is given off during sludge digestion. Müller[5] studied the operation of a sludge digestion tank at Halle, Germany, which had a capacity of 37,500 cu. ft., and reported the heat given off during digestion for the 11-month period from January to November, 1930, to be 83.5 million B. t. u., or 6.7 B. t. u. per cu. ft. of sludge tank volume per day.

Contrasted with these conclusions is the recent work of Fair and Moore,[6] who state that sludge digestion "may be either exothermic or endothermic, depending on conditions," and "that the main processes involved are potentially endothermic, and that the highest thermodynamic efficiency is attained when digestion proceeds essentially as an endothermic reaction."

In order to obtain further information about this problem a series of experiments have been conducted since December, 1930, in the laboratory at the Baltimore sewage works. The first part of the work consisted in endeavoring to check the observations of Sierp. Although it was possible to duplicate his results, it was soon found that the use of apparatus such as he employed led to erroneous conclusions. Furthermore, from the observations made with a modified and more suitable form of equipment it was impossible to state whether sludge digestion was endothermic or exothermic. Consequently it was necessary to resort to more sensitive apparatus. Therefore, during the second part of the experiments, digesting sludge was placed in calorimeters in a constant temperature room, and the change in temperature of the sludge was observed daily. Four groups of experiments were made. The results of this work indicate that for a short period at the beginning of digestion the temperature of the sludge usually rises, showing that heat is evolved. This condition, however, is soon followed by a lowering of the temperature, which shows that heat is absorbed. On the whole the process is more endothermic than exothermic.

Part I

The experimental work as a whole falls into two parts. The first part consisted in determining roughly whether digesting sludge evolves sufficient heat so that it can be measured by other than the most delicate apparatus. The method adopted by Sierp was followed. He used two metal containers, B and C, each with a capacity of 60 liters, and placed them on insulating blocks in the bottom of a larger receptacle, A, which was filled with water. Vessel B contained water, and vessel C digesting sewage sludge. The temperature in both of the 60-liter containers was brought to 20° C., and the temperature of the surrounding water in vessel A was kept at 0° C. The temperature of the water in B and the sludge in C eventually dropped to 0° C. The water reached this temperature much more quickly than the sludge, due to convection currents, which are present only to a limited extent in sludge. When the ice bath in container A was replaced with water kept at 20° C., vessel B took the same length of time to warm up as to cool. With sludge, however, the period required for cooling was much longer than the time for warming. Sierp concludes, therefore, that the "differences between cooling and warming must be due to the generation of heat in the sludge by biological action."

He unfortunately did not use the correct type of apparatus to make his studies, and has, therefore, reached erroneous conclusions. The containers he used had the upper surfaces of the water and the sludge exposed to the atmosphere. He does not state what the temperature of the atmosphere immediately above the apparatus was, but it was presumably

room temperature, possibly in the neighborhood of 20° C. If such were the case, the temperature of the sludge would necessarily increase from 0° to 20° C. faster than it would decrease. While cooling, heat passed from the sludge out through the bottom and the four walls of the container to the ice bath. At the same time this drop in temperature was

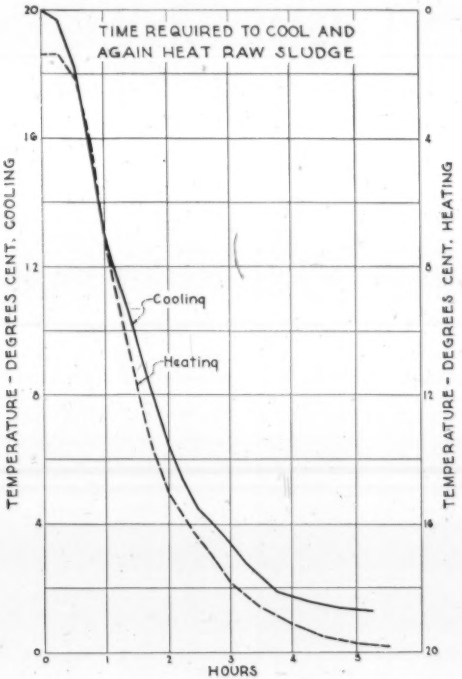

FIG. 1.

retarded by heat absorbed through the surface of the sludge from the atmosphere. On the other hand when the temperature of the sludge was raised from 0° to 20° C., heat passed not only through the bottom and walls of the container but also through the surface of the sludge. In this instance the heat from the atmosphere accelerated the temperature change instead of retarding the temperature change.

The work done by Sierp was repeated at the Baltimore sewage works except that a different type of container was used, which consisted of covered sheet metal cans, each $7^1/_2$ in. high and $4^5/_8$ in. in diameter. Two small holes were drilled in the cover, to each of which a small vertical pipe was attached. In one pipe an incubator thermometer was suspended for

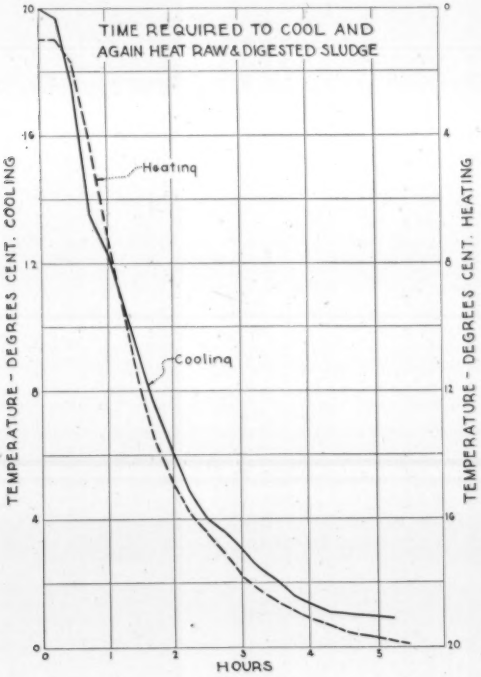

FIG. 2.

observing the temperature of the contents of the can. The other pipe permitted the liquid to expand and contract during heating and cooling. Four cans in all were used. The first contained raw sludge, the second digested solids, the third a one-to-one mixture of these two materials and the fourth contained sludge that was digesting very actively. Each vessel was completely filled so as to eliminate any air space at the top.

They were all brought to 20° C., and then completely submerged in a water-bath, kept at 0° C. The temperature of the sludge in each vessel was observed every 15 minutes. As indicated by Figures 1 to 4, inclusive, the temperatures of the sludges at the end of $5^1/_2$ hrs. varied from 0.9° to 1.3° C. The ice water in the bath was then replaced by water,

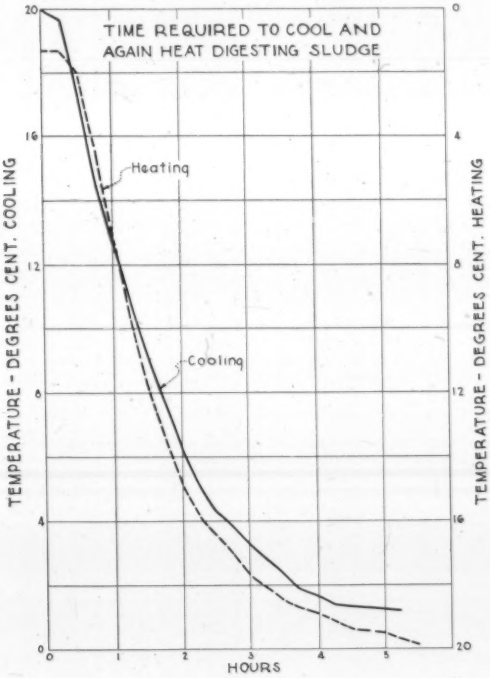

FIG. 3.

which was maintained at 20° C. At the end of $5^1/_2$ hrs. the temperatures of all of the sludges varied from a minimum of 19.7° to a maximum of 19.9° C. From the results of this work it is impossible to state whether digesting sludge is endothermic or exothermic, as the apparatus and methods used were not sufficiently sensitive to make close observations. As the equipment used during the experiments was of a more appropriate

design than that employed by Sierp, the results obtained have greater significance. In order to obtain more accurate information regarding this problem, the temperature changes of digesting sludge placed in calorimeters were observed.

One of the questions, which is closely related either to the heating or

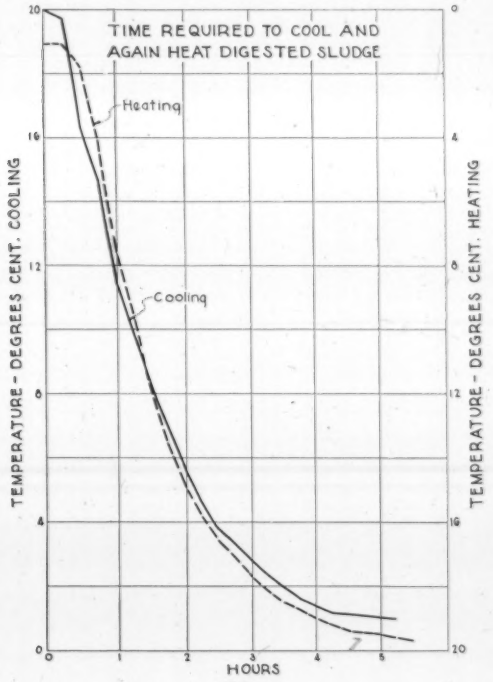

FIG. 4.

the cooling of sludge, deals with the transfer of heat by conduction and convection through this material. The nature of sludge is such that due to its viscous properties the transfer of heat through it by convection is much slower than through water. In order to determine the conductivity of sludge three samples were sent to the Bureau of Standards in Washington. The materials used in the observations were raw, semi-digested and

digested sludges. The moistures averaged 87.4 per cent, and the volatile matter, as indicated in Table I, varied from 51.1 to 70.8 per cent. The thermal conductivity was a minimum of 4.5 in the raw solids, and a maximum in the semi-digested sludge of 5.1. The average conductivity of the three materials was 4.78 or 14 per cent higher than that of water. It is believed that this higher conductivity is due to the presence of organic and inorganic substances, which have a higher conductivity than water.

TABLE I

THERMAL CONDUCTIVITY OF SEWAGE SLUDGE

Character of Sludge	Moisture, %	Volatile Matter, %	Ether Soluble Matter, %	Thermal Conductivity*
Raw Sludge	87.4	70.8	26.5	4.5
Semi-digested	87.4	65.1	18.6	5.1
Digested	87.3	51.1	8.2	4.7

* The thermal conductivity is the amount of heat in B. t. u. that will flow through a square foot area in one hour if the temperature drop through the material is 1° F. per inch of thickness. The thermal conductivity for water is 4.1.

Part II

The second part of the experiments consisted of a study of the temperature changes of sludge placed in calorimeters, and computation of the quantity of heat absorbed and given off during digestion. The raw sludge used was obtained from the preliminary settling tanks at the Baltimore sewage works, and the ripe material was drawn from one of the digestion tanks. The quantities and the characteristics of the sludges both before and after digestion are given in Table II.

TABLE II

CHARACTERISTICS OF SLUDGES BEFORE AND AFTER DIGESTION

Experiment No.	Quantity of Wet Sludge Used, Grams	Sludge at Beginning of Experiments*			Digested Sludge		
		Moisture, %	Volatile Matter, %	Ether Soluble Matter, %	Moisture, %	Volatile Matter, %	Ether Soluble Matter, %
1	525	88.2	65.4	23.1	91.3	51.3	8.9
2	550	90.8	68.9	21.5	93.5	54.9	10.6
3	480	91.1	62.9	16.7	..	53.7	..
4	520	91.6	71.2	22.9	94.5	53.2	12.1

* Raw sludge consisting of 1 part by weight of digested material was mixed with two parts of raw sludge (dry volatile solids basis) except in Test No. 4 where 1 part by weight of wet digested sludge was mixed with 1 part of raw material.

The calorimeters used were made from 850-cc. Dewar flasks, each of which was placed in a wooden box with the space between the box and flask filled with sawdust. Paraffin was poured around the top of the

flask to prevent the escape of sawdust. Beckmann thermometers, which were calibrated before and after each set of observations, and which could be read to 0.002° C., were used to measure the temperatures. The calorimeters were kept in a constant temperature room at 28° ± 1° C.

The general procedure relative to the study of the interchange of heat to and from the sludge was that adopted by Hill[7] for determining the heat generated by physiological and bacteriological actions. He suggested

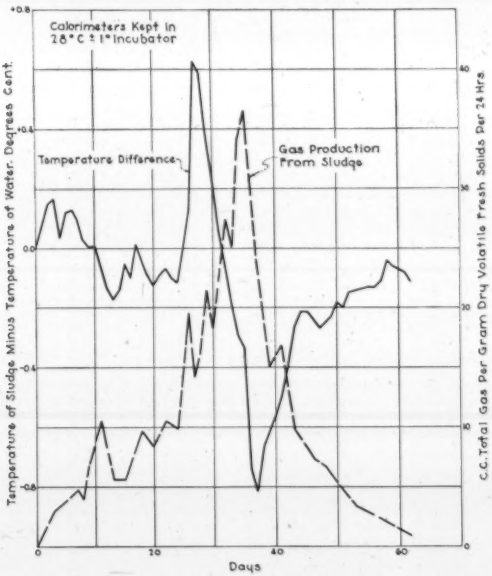

FIG. 5.—Experiment 1. Difference in Temperatures Between Calorimeters Containing Sludge and Water.

the use of two calorimeters. In one is put the material, which will either generate or lose heat, and in the other is placed water. The quantity of water used is such that the coefficient of the temperature loss in each of the two calorimeters is the same. Under this condition Hill has proved that

$$H = C\left[(T - T^1) - (A - A^1) + \int_o^t K(T - T^1)dt\right]$$

where

H = total heat liberated
C = heat capacity of calorimeter and its contents
T = temperature of experimental material in calorimeter
T^1 = temperature of water in control calorimeter
A = initial temperature of T
A^1 = initial temperature of T^1
K = coefficient of loss of temperature of calorimeter
t = time interval

The expression $\int_o^t K\ (T-T^1)\ dt$ can be found in the following manner. The difference in temperature, $T-T^1$, of the two calorimeters is observed

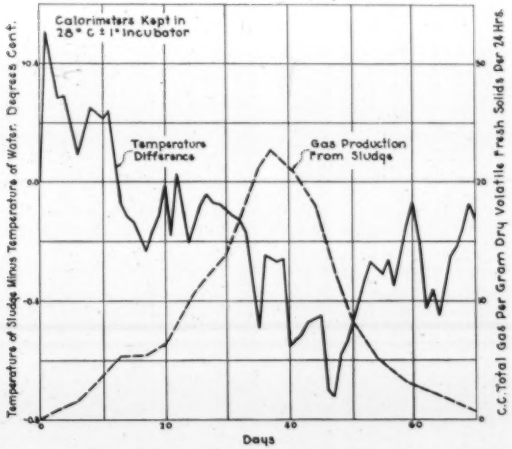

FIG. 6.—Experiment 2. Difference in Temperatures Between Calorimeters Containing Sludge and Water.

at definite time intervals, and a graph prepared of the observations. Temperature differences are plotted as ordinates and time intervals as abscissas. The area between the curve and the X-axis, therefore, is equal to the above-mentioned integral expression. By the use of the above formula, therefore, it is easy to determine how much heat is absorbed or given out at the end of any period of time during the digestion process.

Four groups of observations were made using the above-mentioned apparatus. The temperatures of the calorimeters containing sludge and water were observed daily except on Sundays and holidays. Further-

more, the gas was measured and analyzed. The results are shown graphically in Figures 5 to 8. These curves show the daily quantity of gas produced by the sludge, and also the difference in temperature between the sludge and the water in the two calorimeters. Plus temperature values indicate that the sludge produced heat, and negative values the opposite condition. During each of the experiments digestion was exothermic at the beginning; toward the middle and the end, however, the process was endothermic. As a general rule the quantity of heat absorbed varied in amount directly with the volume of gas produced. This fact is in accord with the statement of Fair and Moore that when digestion is rapid the process is endothermic, whereas at the beginning of digestion, when the process is exothermic, decomposition is slow and the quantity of gas produced is small.

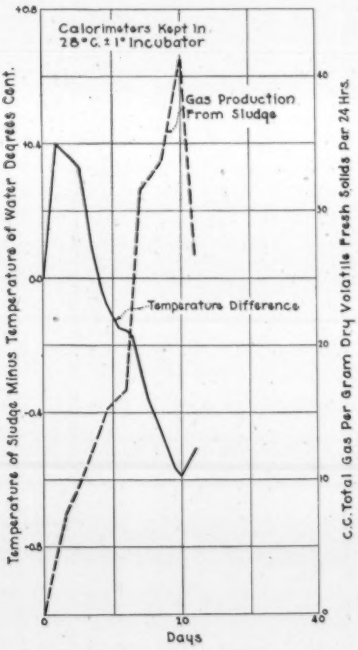

FIG. 7.—Experiment 3. Difference in Temperatures Between Calorimeters Containing Sludge and Water.

It was thought that perhaps one reason why the sludge absorbed heat during high gas yields was because water vapor escaped from the surface of the sludge as the gas was generated. In order to see if this were true, the gas was first passed through calcium chloride, the weights of which were observed. No increase in the weights of this chemical was noted during the tests.

Finally, in order to have the sludge, which was in one calorimeter, and the water in the other as far as possible in exactly the same conditions, the gas produced by the sludge was passed through the water in the second calorimeter. The difference in temperatures between these two calorimeters is shown by the solid line in Figure 8 (designated Experiment 4A). The temperature difference between the sludge and a third calorimeter

Table III

Heat Balance of Solids in Sewage Sludge

Note: Heat Units Are Expressed in Calories per Gram of *Total Dry Solids*

Experiment No. (1)	Heat Value of Sludge At Beginning of Test, Cal./Gram (2)	Heat Value of Sludge At End of Test, Cal./Gram (3)	Heat Value of CH_4 Produced, Cal./Gram (4)	Heat Interchange During Digestion: Heat Given Off Percentage of Heat Value of Sludge at Beginning of Test, Cal./Gram (5)	% (6)	Heat Absorbed Percentage of Heat Value of Sludge at Beginning of Test, Cal./Gram (7)	% (8)	Total Heat Interchange Column (7) − (5) Percentage of Heat Value of Sludge at Beginning of Test, Cal./Gram (9)	% (10)	Summation of Heat Values, Cols. (3) + (4) + (9), Cal./Gram (11)
1	4723	2858	1985	21.1	0.4	74.5	1.6	53.4	1.2	4896
2	4808	2430	1900	28.8	0.6	155.7	3.2	126.9	2.6	4457
3	3672	2481	1357	20.0	0.5	56.7	1.5	36.7	1.0	3875
4 A	4473	2552	1947	29.5	0.6	109.2	2.4	79.7	1.8	4579
4 B	4473	2552	1947	43.3	1.0	99.1	2.2	55.8	1.2	4555

Table IV

Heat Balance of Solids in Sewage Sludge

Note: Heat Units Are Expressed in Calories per Gram of *Total Dry Volatile Solids*

Experiment No. (1)	Heat Value of Sludge At Beginning of Test, Cal./Gram (2)	Heat Value of Sludge At End of Test, Cal./Gram (3)	Heat Value of CH_4 Produced, Cal./Gram (4)	Heat Interchange During Digestion: Heat Given Off Percentage of Heat Value of Sludge at Beginning of Test, Cal./Gram (5)	% (6)	Heat Absorbed Percentage of Heat Value of Sludge at Beginning of Test, Cal./Gram (7)	% (8)	Total Heat Interchange Column (7) − (5) Percentage of Heat Value of Sludge at Beginning of Test, Cal./Gram (9)	% (10)	Summation of Heat Values Columns (3) + (4) + (9), Cal./Gram (11)
1	7220	5569	3040	32.2	0.4	113.9	1.6	81.7	1.2	8691
2	7021	4428	2774	42.0	0.6	227.4	3.2	185.4	2.6	7387
3	5834	...	2157	31.8	0.5	90.0	1.5	58.2	1.0	...
4 A	6282	4801	2726	41.4	0.7	153.4	2.4	112.0	1.8	7639
4 B	6282	4801	2726	60.9	1.0	139.1	2.2	78.2	1.2	7605

containing water, through which gas was not passed, is shown by the dotted line in this figure (designated Experiment 4B). The two curves follow each other quite closely, the temperature difference averaging about 0.03° to 0.05° C. It is thought that some small amount of evaporation took place, for during about 60 per cent of the time the calorimeter containing water, through which gas was passed, had a lower temperature than the other water calorimeter, into which gas was not introduced. It is possible, therefore, that the results for Experiment 4A, given in Tables III, IV and V, are more representative of true conditions than

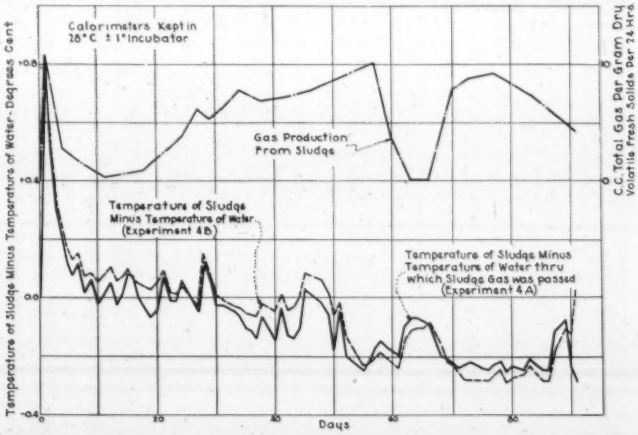
Calorimeters Kept in 28°C ± 1° Incubator
Gas Production From Sludge
Temperature of Sludge Minus Temperature of Water (Experiment 4B)
Temperature of Sludge Minus Temperature of Water thru which Sludge Gas was passed (Experiment 4A)
Temperature of Sludge Minus Temperature of Water - Degrees Cent
C.C. Total Gas Per Gram Dry Volatile Fresh Solids Per 24 Hrs.
+0.8
+0.4
0.0
-0.4
0
20
40
60
80
Days

FIG. 8.—Experiment 4. Difference in Temperatures Between Calorimeters Containing Sludge and Water. (Three calorimeters were used. One contained sludge and the other two water. The gas produced by the sludge was passed through one of the calorimeters containing water.)

those for Experiments 1, 2, 3 and 4B. All of the observations and calculations, however, have been given as they clearly indicate that the sludge digestion process as a whole is endothermic.

From the curves shown in Figures 5 to 8 and with the aid of the above-mentioned formula the total amount of heat given off and absorbed during the entire period of digestion was calculated. As indicated in Table III, the heat given off varied from 20.0 to 43.3 calories per gram of total dry solids or from 31.8 to 60.9 calories (see Table IV) per gram of total dry volatile solids. The heat absorbed varied from 56.7 to 155.7 calories per gram of total dry solids or from 90.0 to 227.4 calories per gram of total

TABLE V

HEAT INTERCHANGE DURING SLUDGE DIGESTION

NOTE: Heat Units Are Expressed in Calories per Gram of Total Dry Volatile Solids Lost in Digestion

Experiment No. (1)	Heat Given Off, Cal./Gram (2)	Heat Absorbed, Cal./Gram (3)	Total Heat Interchange Column (3) − (2), Cal./Gram (4)
1	76.8	271.5	194.7
2	98.0	530.6	432.6
4 A	81.2	301.0	219.8
4 B	119.4	273.0	153.6

dry volatile solids. The heat values of the sludge at the beginning and the end of the experiments, based on total dry solids and also on total dry volatile solids, are given in Columns 2 and 3 of Tables III and IV. Column 2 in these two tables is a summation of the heat in the digested sludge, the methane produced during digestion and the heat absorbed minus the heat given off. These summations as given in Table III are in comparatively close agreement with the heat values of the material at the beginning of the tests. The differences between the two sets of determinations vary from 1.8 to 7.2 per cent, which is not great considering the numerous factors which may introduce errors in the results. It should be noted that the heat given off varied from 0.4 to 1.0 per cent and the heat absorbed varied from 1.5 to 3.2 per cent of the total heat value of the material at the beginning of the tests. Table V shows the heat given off and absorbed, based on the amount of volatile solids lost or destroyed in the digestion process. In this instance the heat given off averaged 93.9 calories and the heat absorbed 344 calories per gram of volatile solids destroyed.

A study of the results obtained indicate that sludge digestion is exothermic during the early stages of decomposition. As the process continues, however, digestion becomes endothermic. During the entire stage of decomposition more heat is absorbed than is given off.

The sewage works is under the general supervision of B. L. Crozier, chief engineer, Department of Public Works, and G. E. Finck, sewerage engineer, with G. K. Armeling, superintendent. Acknowledgments are due to J. W. Bushman, junior chemist, who assisted in the laboratory work.

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Heat Losses from Sludge Digestion Tanks*

II. Field Observations at Freehold, New Jersey

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In a previous paper[1] laboratory studies were reported dealing with the relative radiations of heat from sludge at different temperatures. It was shown that the rate of cooling of sludge in air was directly proportional to the difference in temperature between the sludge and the surrounding air. Most of the modern sludge digestion tanks are either buried in the ground or have an earth embankment around the tanks. The question arose whether such tanks would lose heat similarly to tanks placed in the air, or whether such embankments afford sufficient insulation to prevent appreciable heat losses. In the laboratory experiments it was also shown that the sludge in the center of a container cools considerably more slowly than the entire mass of sludge, but that the same law defines the rate of cooling for the center sludge or the entire mass. If a significant difference in cooling is found in large tanks the construction and placement of heating coils and circulation of the sludge mass might be affected.

Heat losses from low and high temperature digestion tanks were found to have a definite relation to the temperature of the tank contents. A more or less accurate measurement of gas production and utilization in an actually operating municipal plant would be of interest, not only in respect to a check on the laboratory experiments, but also in regard to the relative heat losses and the efficiency to be expected. The outcome of such investigations would lead necessarily to the question of proper insulation for all digestion tanks, whether or not they are artificially heated.

Description of Plant

The Freehold, N. J., sewage treatment plant was used for the observations reported herein. Mr. W. G. Schiverea, the Freehold Borough Engineer, who designed the plant and under whose direction it was built, was kind enough to write for us the following description.

"Freehold has a population of 7000. The treatment plant is designed for 600,000 gallons per day and consists of a screen chamber, two primary settling tanks equipped with Dorr clarifiers, wet well, sprinkling filter, secondary settling tank, sludge digestion tank with Dorr mechanism, sludge drying beds and pump house with laboratory. The primary settling tanks are designed for a 4-hour detention period, but only one

* *Journal Series Paper, N. J. Agr. Expt. Sta., Dept. Sewage Research.*

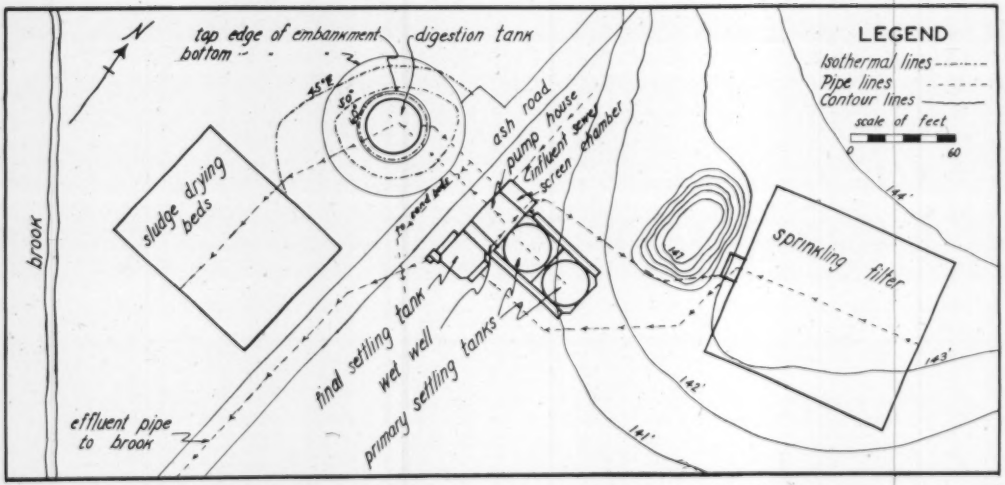

FIG. 1.—General Layout of Plant, with Heat Penetration Lines Superimposed on Digester.

tank is being used. The gas from the digester is used for heating the pump house and the digestion tank. Digestion capacity available is 1.5 cubic feet per capita. The sprinkling filters, 8 feet deep, receive 300,000 gallons per acre foot of filtering material.

The plant was placed in service Nov. 1, 1930. Practically the entire population is connected and the average daily flow amounts to 350,000 gallons per day. A large rug mill is located in the Borough and the waste water was originally discharged into the sewer, but at present most of the waste is treated separately at the old treatment plant. This waste is given preliminary treatment at the mill. Although the plant is located near the built-up sections and the sewage should be fresh, it is usually black in color and contains considerable quantities of hydrogen sulphide. Pre-chlorination and final chlorination is practiced.

FIG. 2.—Clarifiers and Pumphouse.

The cost of the plant was $87,000 including 2000 feet of 18-inch sewer constructed by the Borough force. A general layout of the plant is shown in Figure 1, while the digester and clarifiers are shown in the accompanying photographs (Figures 2 and 3). The embankment of the digester is sodded."

Temperature Variations Within the Digestion Tank

It has been reported by us and also by Downes[2] that the temperature of the sludge present in a heated tank may vary considerably, showing an apparent stratification. The present experiments were conducted by taking temperatures in the tank with a recording thermometer consisting of a sensitive bulb connected to a recording mechanism by means of a flexible, insulated cable. The recording mechanism consisted essentially of a slowly revolving circular paper chart, operated by clockwork, on

which the temperature of the sensitive bulb was automatically marked with a pen whose movements were controlled directly by the temperature of the bulb.

The bulb was lowered into the digestion tank through a manhole in the cover and the temperatures recorded at one-foot intervals from top to bottom. While taking these readings the bulb was at all times about three feet from the inside wall of the tank. Temperatures were also taken at one-foot intervals vertically near the center of the tank by lowering the bulb through the gas dome, which was temporarily removed. The results of one of these tests are plotted in Figure 4. Remembering that the limit of accuracy of the thermometer used was plus or minus one degree Fahrenheit, it will be noticed that the variation in temperature across the tank at any given elevation was very small. Vertically, the

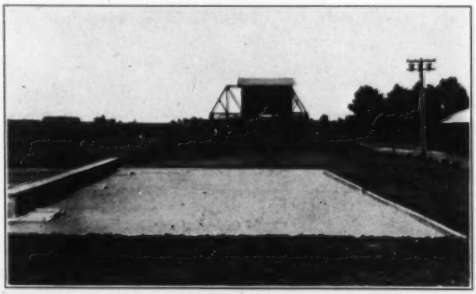

FIG. 3.—Digester with Sodded Embankment.

temperature varied considerably. From the bottom to 11 feet up, the temperature remained practically constant; between 11 and 12 feet it suddenly dropped 8° F.; between 12 and 14 feet it remained practically constant; and from 14 feet to the top it gradually decreased.

Samples of the tank contents, taken at the same points where temperatures were recorded, were analyzed for solids and ash. The results indicated a decrease in solids and ash corresponding to the sudden drop in temperature noted. On several other occasions when temperatures were taken throughout the tank, this sudden drop in temperature was always accompanied by a decrease in per cent solids, but at different levels in the tank on different occasions. The temperature drop usually amounted to 10° F. and took place within an interval of one foot, measured vertically.

From the results it may be seen that the temperature increased approxi-

mately 1° F. for an increase of 1.0 per cent in ash content, or 0.5 per cent increase in solids. However, when the results are examined there is no such correlation between temperature, solids and ash in the sludge layers nearer the bottom of the tank, or anywhere outside of the presumably

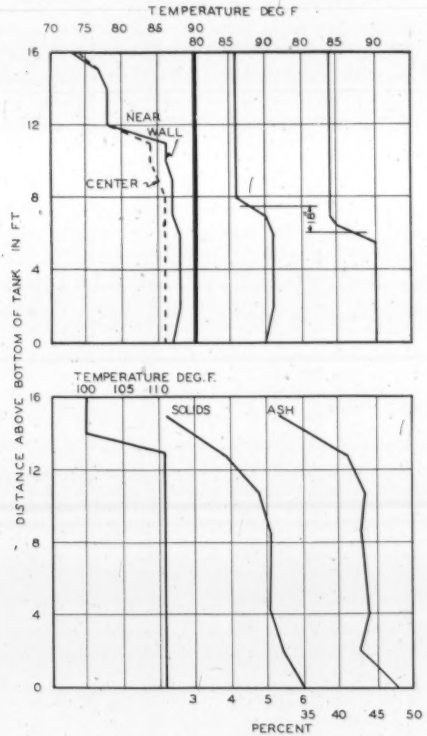

FIG. 4.—Variation in Temperature, Solids and Ash at Different Levels in the Tank.

active zone of digestion. This led us to conclude that the temperature variation took place at the supernatant-sludge interface, where decomposition is most active. It would be possible therefore that two factors were involved, namely (1) sludge absorbs and retains heat, and (2) heat

is produced during the decomposition processes. It has been assumed that the heat supplied by the heating coils traveled upward and was retained by the sludge layer. To confirm this, the experiment was repeated on a day when sludge was to be drawn, readings being taken before and after 18 inches of sludge were removed (that is, after the surface of the liquid in the tank had dropped 18 inches by actual measurement). It will be noticed, Figure 4, that the level where the sudden temperature drop occurred was also lowered 18 inches. These experiments were repeated many times with the same results. It is evident, therefore, that the temperature difference is not caused by convection of the heat to a specific place in the tank, but is related to the sludge concentration (ash and/or solids) and to the zone of actively decomposing sludge. If the activity of the decomposing sludge is a factor, we should be able to measure the heat produced by solids decomposing under anaerobic conditions and also the rate of heat production, which would vary with the rate of the total digestion activities. These measurements have been made and this question will be the subject of a following article in this series.

From the experiments it is clear that the contents of the digestion tank consist of two distinct layers of different temperature, the temperatures within the layers being practically constant both horizontally and vertically. The difference in temperature between the layers averaged for ordinary operating conditions about 10° F., the hotter layer being toward the bottom. Several months later when the temperature of the lower layer was raised to about 120° F., the same 10° difference persisted, but when the heat was turned off and the tank allowed to cool for two weeks, the upper layer cooled more quickly than the lower one until at the time the heat was turned on again, the difference was only 4° F.

Heat Losses from the Digestion Tank

For a study of the actual heat losses of the digestion tank, records were taken, over a period of four months, of the heat applied, volume and weight of solids and water introduced and drawn, and temperatures of the soil, air and tank contents.

The reinforced concrete digestion tank is 30 feet inside diameter and 17 feet deep as shown in Figure 7. It is equipped with a Dorr stirring mechanism and surrounded by an earthen embankment to reduce heat losses. Heat is supplied to the tank by a hot water heating system, which utilizes as fuel a portion of the gas produced by the digestion processes. The hot water is circulated by a small centrifugal pump of 6.5 gallons per minute capacity through five coils of 2-inch diameter pipe arranged in the form of a spiral and fastened to the inside walls of the tank as shown.

Fresh solids are pumped daily from the clarifiers into the digestion tank

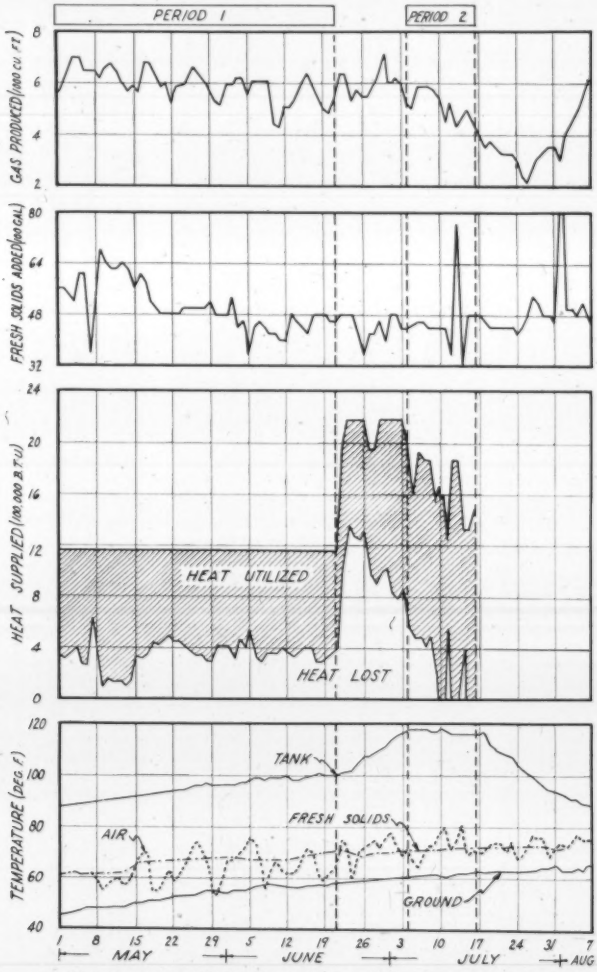

FIG. 5.—Solids Added. Gas Produced and Heat Exchange.

through a pipe which discharges just below the roof. The introduced sludge displaces supernatant liquor, which flows out through the overflow pipe onto sand beds. The tank is thus kept filled at all times. Careful records were kept of the volume of fresh solids added to the tank each day by recording the number of minutes the sludge pump was operated. The amount of heat added to the tank was determined by keeping a record of the temperature of the heating water as it entered and left the coils in the tank. The temperature of the material in the tank was determined with a recording thermometer, the bulb of which was fastened a few inches from the inside wall of the tank and about 10 feet below the roof. The air and normal ground temperatures were also recorded with similar instruments. The bulb of the air thermometer was suspended about 2 feet above the tank, under the wooden superstructure which houses the Dorr mechanism, the bulb thus recording temperatures in the shade at all times. The bulb of the ground temperature thermometer was buried three feet in the ground several hundred feet away from any tank which might influence the normal ground temperature. Temperatures were also taken from time to time of the material added to the digestion tank.

As mentioned previously there were two distinct layers of different temperatures in the tank. Since the fresh solids were added at the top most of them entered the upper layer, but no doubt a portion settled to the lower layer where the temperature was higher. During 114 days the level of the sludge in the tank was raised 90 inches (allowance being made for sludge drawn). During this period 450,800 gallons of sludge were pumped into the tank. If all this sludge had remained in the tank the level would have been raised 1020 inches. Therefore, the proportion of sludge which became ripe and digesting sludge and reached the lower layer was 9 per cent by volume; the remainder (water) went out through the overflow. For purposes of computation it was assumed that 9 per cent by volume found its way to the lower level and therefore was raised 10° F. higher in temperature than the remaining 90 per cent.

First Period

For convenience, the entire period of observation is divided into periods. A summary of observations made during the first period of 52 days is as follows: (These results are shown in graphic form in Figure 5.)

Average temperature of sludge in tank (lower layer)	=	94° F.
Average temperature of ground	=	54° F.
Average temperature of air	=	65° F.
Average temperature of fresh solids added daily	=	66° F.
Total volume of fresh solids added to tank	=	221,000 gal.
Weight of fresh solids added to tank	=	1,850,000 lbs.
Volume of circulated heating water	=	1,620 cu. ft. per day

Average temperature difference between incoming and outgoing water	=	15°
Heat supplied daily	=	1,172,000 B. t. u.
Total heat added	=	60,944,000 B. t. u.
Total heat utilized	=	35,000,000 B. t. u.
Total heat lost	=	25,944,000 B. t. u.
Heat utilized daily	=	828,000 B. t. u. (average)
Heat lost daily	=	344,000 B. t. u. (average)
Per cent heat utilized	=	70
Per cent heat lost	=	30

On May 1, 1932, the temperature of the tank was 87° F., as shown in Figure 5. It increased steadily until on June 21 it was 100° F. (13° higher). The ground temperature increased during the same period from 45 to 58 (13° higher). It is interesting to note that the lines representing the two temperature records in Figure 5 are practically parallel, while the line representing the average daily air temperatures during this period is very irregular. Keeping in mind the fact that the heat added to the tank daily during this same period was practically constant, it would appear that the temperature of the surrounding ground has a considerable effect on the tank temperature while that of the air has very little direct effect.

Second Period

At the end of the first or low temperature period, the temperature of the heating water was increased by using more gas in the heater. This in turn raised the temperature of the digestion tank, as shown in Figure 5, to 118° F., which temperature was maintained until July 18.

Average temperature of sludge in tank (lower layer)	=	117° F.
Average temperature of ground	=	62° F.
Average temperature of air	=	73° F.
Average temperature of fresh solids added daily	=	71° F.
Total volume of fresh solids added to tank	=	58,600 gal.
Total weight of fresh solids added to tank	=	490,000 lbs.
Volume of circulated heating water	=	1,250 cu. ft. per day
Total heat added during period = summation of daily temperature differences between ingoing and outgoing heating water	=	21,093,750 B. t. u.
Average heat supplied daily	=	1,622,600 B. t. u.

Assuming as before that 9 per cent of the fresh solids added settled to the higher temperature zone in the tank:

Total heat utilized	=	17,906,000 B. t. u.
Heat utilized daily	=	1,377,000 B. t. u.
Total heat lost	=	3,187,750 B. t. u.
Heat lost daily	=	245,000 B. t. u.
Per cent heat used	=	85
Per cent heat lost	=	15

The most significant figures obtained have been condensed in Table I.

TABLE I

CONDENSED SUMMARY OF RESULTS OBTAINED

	Period 1	Period 2
Average Temperature Difference Between Tank and Ground	40° F.	55° F.
Heat Added Daily, B. t. u.	1,172,000	1,622,600
Heat Used Daily, B. t. u.	828,000	1,377,000
Heat Lost Daily, B. t. u.	344,000	245,600
Per Cent Heat Used	70	85
Per Cent Heat Lost	30	15
Heat Added per Degree Difference in Temperature Between Tank and Ground (B. t. u.)	29,300	29,500
Discrepancy, Per Cent		0.68

It is evident that the heat required per degree difference in temperature between the tank and ground was practically constant in both periods, but that the heat required to maintain the digestion tank at a given temperature varied directly as the temperature difference between the tank and ground. Comparisons with the air temperature show that variations in air temperature had little direct effect except as it affected the ground temperature. It should be kept in mind that the tank is covered and the area exposed is comparatively small in relation to the total tank surface surrounded by the soil.

Cooling the Sludge Digestion Tank

On July 18, the heat was turned off and the digestion tank allowed to cool, the recording thermometer in the tank registering the rate of cooling of the sludge. During this time regular additions of fresh solids were continued and the supernatant liquor displaced.

The average daily temperatures of the cooling tank are plotted against time in Figure 5, and the logarithms of the temperature differences between the tank and the ground against time in Figure 6. Within the limits of accuracy of the instruments used, the theoretical curve, shown as a solid line in Figure 6, developed in our laboratory (2) in experiments on the rate of cooling of sludge, agrees very closely with the actual data obtained in the field.

The equation of the cooling curve mentioned is

$$\phi = \phi_1 e^{-kT}$$

Where ϕ = Difference in temperature between cooling sludge and surrounding medium (in this case earth).

ϕ_1 = Initial difference in temperature between the sludge and the surrounding medium.

T = Time, in days, during which the sludge cools from ϕ to ϕ_1.

e = Naperian base = 2.71828.

k = A constant that varies with the cooling material, and the size, shape and composition of the tank.

The constant k for this particular case is determined from Figure 6 as follows:

$$\phi = \phi_1 e^{-kT}$$

Therefore, $\log \phi = \log \phi_1 - kT \log e$
(all logarithms being to the base 10)

Then $k = \dfrac{\log \phi_1 - \log \phi}{T \log e}$

Taking T as the interval from 0 to 16 days:

$T = 16$; $\phi_1 = 50.5°$ F.; $\phi = 27°$

Hence $k = 0.0391$

Rate of cooling $= \dfrac{d\phi}{dT} = -k\phi = -0.0391$ degree per day

During the first period the average temperature difference (ϕ) between the digestion tank and soil was 40° F. Therefore the rate of cooling ac-

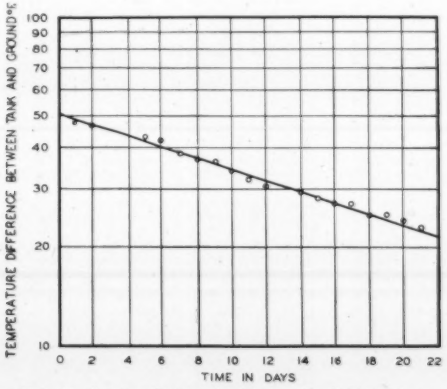

FIG. 6.—Cooling Curve of Digestion Tank Plotted on Semi-Logarithmic Coördinates.

cording to the given formula was 1.564 degrees per day. As the volume of sludge in the tank was 12,000 cu. ft., the theoretical heat loss was 1,173,000 B. t. u. per day. The actual heat added to the tank to overcome this loss computed on the basis of hot water circulated in the digestion tank was 1,172,000 B. t. u. per day.

During the second or high temperature period, the temperature difference ϕ was equal to 55° F., and the theoretical rate of cooling was 2.1505 degrees per day or 1,612,875 B. t. u. per day. The actual heat required computed on the basis of circulating water was 1,622,596 B. t. u. per day,

It can be seen that the theoretical and actual values check each other very closely, as they should, for if sufficient heat is added to equalize the rate at which it is being lost and consumed, the temperature of the tank will remain constant.

Heat Penetration Into Surrounding Soil

In order to determine how far the heat from the digestion tank penetrated into the earthen embankment surrounding the tank, recording

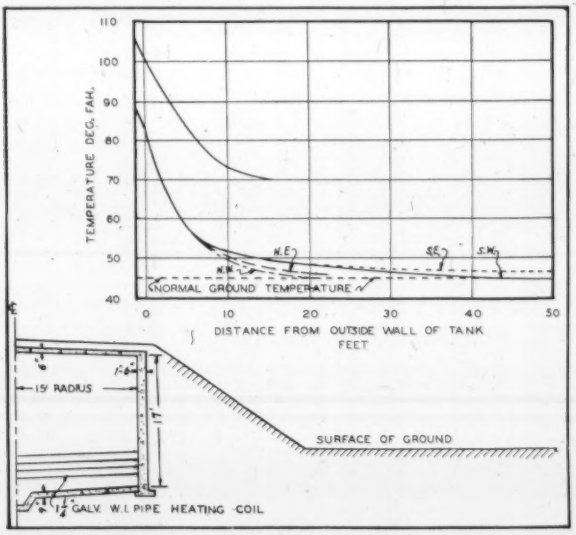

FIG. 7.—Heat Penetration Into Soil Surrounding Digestion Tank.

thermometers were buried in the soil at different depths and at various distances from the tank. The normal ground temperature was determined by means of another recording thermometer bulb buried three feet in the ground and several hundred feet from any structures which would influence the temperature recorded. Three feet was selected as it was found by experiment that at that depth the daily variations in air temperature had little effect on the temperatures recorded, the daily ground temperature variations never exceeding 1° F.

Temperature Variations Vertically.—Readings were taken at 1-foot

intervals vertically in the embankment to a depth of 12 feet. There was a considerable variation in the first 2 feet below the surface due to changing air temperature, but below that depth the temperature remained constant provided the distance and direction from the outside wall of the tank remained the same. This indicates that the heat conducted away from the walls of the tank travels out horizontally to the edge of the embankment and does not escape by taking a shorter inclined path. Therefore, in studying heat penetration it is immaterial how deep the thermometers are buried in the soil surrounding the tank, provided they are at least 3 feet below the surface.

Temperature Variations Horizontally.—The heat from the digestion tank did not penetrate equal distances into the soil in all directions. Southeast of the tank the heat could be traced 50 feet from the outside wall, that is, the temperature of the ground 3 feet below the surface at that distance was still 2° above normal ground temperature. Southwest of the tank it penetrated 45 feet, whereas northeast it penetrated only 22 feet and northwest 20 feet. In the latter case the heat did not even reach the edge of the embankment.

The results of these temperature studies are plotted in Figure 7. The lower set of curves show the penetration of heat when the sludge in the tank was maintained at a temperature of 88.5° F. The upper curve shows the penetration when the tank temperature was 107° F. It will be noticed that the drop in temperature through the concrete tank wall was 6° F. in both cases.

Gas Production and Utilization

The records kept of the amount of gas produced, the time of pumping, and analyses of the sludge and gas (Figure 5) allow a rather close estimate of the gas produced per pound of dry solids and the total heat produced. These results can be checked against the amounts of water heated and circulated, the temperature of the tank and the rise in temperature of the surrounding soil (also in Figure 5). The average heat value of the gas produced was 600 B. t. u.

Gas Production.—Following the same divisions as previously, namely, a low and high temperature period, the results were as follows:

FIRST PERIOD

Total volume of gas produced	=	304,100 cu. ft.
Volume of fresh solids added to digestion tank	=	221,000 gal.
Average solids content of solids	=	2 per cent
Weight of dry solids added	=	37,000 lbs.
Gas produced per pound of dry solids	=	8.2 cu. ft.
Volatile matter in solids (dry basis)	=	77 per cent
Gas produced per pound of volatile matter	=	10.7 cu. ft.
Heat value of gas produced	=	182,460,000 B. t. u.

SECOND PERIOD

Total volume of gas produced	=	67,200 cu. ft.
Volume of fresh solids added to digestion tank (Solids and volatile matter content same as in period one)	=	58,600 gal.
Weight of dry solids added	=	9,800 lbs.
Gas produced per pound of dry solids	=	6.8 cu. ft.
Gas produced per pound of volatile matter	=	8.9 cu. ft.
Heat value of gas produced	=	28,320,000 B. t. u.

A condensed summary of the results obtained is shown in Table II.

TABLE II

SUMMARY OF GAS PRODUCTION AND UTILIZATION

	Period 1	Period 2
Average Gas Production, Daily, Cu. Ft.	5850	5100
Average Gas Production, Daily, Per Capita, Cu. Ft.	0.8	0.7
Gas Produced per Pound Dry Fresh Solids Added to Tank, Cu. Ft.	8.2	6.8
Per Cent of Gas Utilized for Heating	33.4	74.6
Gas Produced per Pound Volatile Matter Added, Cu. Ft.	10.7	8.9

Discussion

Some of the factors that affect efficient and economical operation of heated sludge digestion tanks are gas production and heat losses. Therefore interest has centered mainly around the volumes and heat values of the gases produced. The studies reported herein bring out some interesting facts. The contents of the digestion tank, consisting of two distinct layers (in general sludge and supernatant liquor), differed in temperature by as much as 10° F. However, within the layers the temperatures were practically constant, both horizontally and vertically. Whether the difference in temperature is due to the solids or ash concentration retaining the heat or due in part to the biological activities is at present of no concern, but it shows clearly where the heating coils should be located. Locating the heating coils on the bottom of the tank, as practiced in some instances, would not appear to be the best, since a mass of material which has already undergone active decomposition is kept at the optimum temperature for digestion. Locating the coils in the supernatant liquor would apparently make for greater heat losses. It is obvious therefore that the heating coils should be located in the zone of most active decomposition, which under ordinary operating conditions would be from one-third to one-half way from the bottom of the tank. It is also probable that the digested sludge would sink to the bottom and be less disturbed by convection currents, with the result of greater compacting. Intensive stirring or mixing of the sludge and supernatant liquor would also produce greater heat losses, whereas gently stirring the di-

gested material present below the heating coils may produce a somewhat denser sludge.

Where a tank is buried in the soil or is protected with an earthen embankment the heat required to maintain the digestion tank at a given temperature varies directly with the temperature difference between the tank and the ground (normal ground temperature). Daily variations in air temperature have in such a case little if any effect on the temperature of the tank contents. However, seasonal variations of the air temperature affect the ground temperature, with the result that increases and decreases of heat losses vary with the seasons. When the tank is wholly or partially in the free air, heat losses vary directly with the difference in temperature between the tank and air, so that greater and more rapid fluctuations of the temperature of the tank contents take place. This leads necessarily to the question of proper insulation of the digestion tanks. In order to study the heat losses from low and high temperature digestion tanks, two properly insulated pilot digestion tanks have been built and are being operated at the Freehold, N. J., treatment plant in the same manner as the large digester, on which the present studies were made. These tanks are placed above ground on the northwest side of a small building in which the heating units are located. The results obtained before and after proper insulation will be reported later.

It is often stated that laboratory experiments cannot be duplicated in the field. This may be correct under certain conditions, but it is extremely interesting to note that the cooling curve obtained by turning off the heat and allowing the large tank to cool agreed with a similar curve obtained in the laboratory by allowing a gallon jug of sludge to cool under constant temperature conditions.

Tests indicated that the heat from the sides of the tank traveled only in a horizontal direction. Nevertheless, the heat from the tank did not penetrate the same distance in all directions, but varied from 20 to 50 feet. The superimposed lines on the plan view of the digestion tank and embankment in Figure 1 show that the heat traveled farthest through the soil in S. E. and S. W. directions. The land surrounding the earthen banked tank is almost level, with a very gentle slope in a southwesterly direction. The natural drainage is in that direction. The surrounding soil was originally of a peaty and iron ore nature mixed with clay. The bottom of the tank is several feet above the groundwater level. It appears, therefore, that the winds coming from the N. W. and N. E. over flat fields cause a more rapid cooling of the embankment on those windy sides. It is possible also that the natural drainage has its effect upon the distance of heat travel in the opposite or S. E. and S. W. directions. Theoretically, this should cause a more rapid cooling of the sludge present on the windy side of the tank but tests made were apparently not deli-

cate enough to detect this. However, it has been observed that during cold weather when the air and ground temperature changed very little, the amount of heat required to maintain the temperature of the tank was less on sunny than on cloudy days. During the second period of experimentation there was almost continually clear weather and the average air temperature was about 8° F. higher than during the first period. The relative heat losses were considerably lower at the higher temperatures than at the lower ones. Since the heat losses from the tank occur horizontally through the embankment it is clear that heat penetration into the embankment from the air would travel similarly with the result of relatively lower heat losses from the tank. Consequently, during cold weather the heat losses are greater, or in other words, the thickness of the soil embankment would prevent rapid fluctuations in the tank temperature but would not prevent heat losses in protracted cold spells any more than if the tank was standing in the open air. However, in a climate where the temperature changes are comparatively rapid a soil embankment would be a factor in heat conservation, although it is clear that this type of insulation is very unsatisfactory.

Gas production at the lower temperature amounted to 8.2 cu. ft. per pound of dry fresh solids added or 0.8 cu. ft. per capita daily. When the temperature of the tank contents was raised for a comparatively short time, gas production decreased to 6.8 cu. ft. per pound of dry fresh solids or 0.7 cu. ft. per capita. This latter period shows the transition from mesophilic to thermophilic digestion. Even during this transition stage only about 75 per cent of the gas produced was utilized for heating. This indicates that under thermophilic conditions, when the digestion time is reduced, gas production would be more than sufficient to maintain the temperature required. However, the experiments in progress on the two pilot plants will undoubtedly give more information than at present available and the drawing of definite conclusions should wait.

Summary

Experiments made at Freehold, N. J., on heat losses from a digestion tank surrounded by an earthen embankment showed that there was a difference in temperature between the sludge and supernatant layers (average 10° F.) but that within these layers the temperature was fairly constant both horizontally and vertically. The heat required to maintain the digestion tank at a given temperature varied directly as the temperature difference between the tank and the ground (normal ground temperature). When the heat was turned off and the tank allowed to cool, the cooling curve agreed with one obtained in the laboratory under carefully controlled conditions. The heat from the digestion tank did not penetrate the same distance in all directions into the surrounding

soil, probably due to wind action and local soil drainage. The heat from the sides of the tank traveled only in a horizontal direction.

Gas production amounted to 8.2 cu. ft. per pound of dry fresh solids or 0.8 cu. ft. per capita daily. The gas utilized for heating the incoming fresh solids and maintaining the tank at an average temperature of 98° F. amounted to only 33.4 per cent of the total gas produced. When the contents of the tank were raised to 118° F. gas production decreased during this transition stage to 6.8 cu. ft. per pound dry fresh solids added or 0.7 cu. ft. per capita daily. The amount of gas needed for raising the temperature of the fresh solids added and maintaining the temperature of the tank was 74.6 per cent of the quantity of gas produced.

The necessity of proper tank insulation for either heated or unheated tanks has been indicated.

Acknowledgment

The authors wish to express their appreciation to Mr. W. J. Schiverea, Borough Engineer, and Mr. Warren Denise, Plant Operator, for their valuable coöperation in the execution of these investigations.

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Comments on Fair and Moore's Articles on "Heat and Energy Relations in the Digestion of Sewage Solids"

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The importance of a recent series of papers[1] in THIS JOURNAL and the engineering and biochemical implications of the results reported have led the writers to make a careful study of the data presented. If bacteria or other organisms devoid of chlorophyl or similar substances and in the absence of sunlight can catalyze reactions which yield products with greater energy content than the starting materials, the discovery of such a fact would be epoch making in the whole field of biochemistry. In the particular field of waste treatment, for example, it would mean that bacterial digestion of sludge would yield more total energy than its incineration.

The writers have been considering this general problem for some time and have felt that energy studies such as these should be preceded by careful fundamental studies on the anaerobic fermentation of a number of the pure substances found in sewage, as well as other compounds known to be produced during the anaerobic degradation of sewage solids. By this method of attack it is possible to study first the simpler pure compounds. The heats of combustion and the still more essential free energy values of practically all of the simpler organic compounds are known. The results obtained from a large number of pure compounds have been interesting and valuable. The methods used in these studies have been described in papers by Neave and Buswell[3,4] and Boruff and Buswell[5,6]. A recent paper by Symons and Buswell[2] (in press) presents data on several compounds and the technique developed for obtaining quantitative results. The information obtained and the technique acquired in these studies are now available for use in the attack on more complex problems, such as the energy changes noted in the anaerobic digestion of mixed materials.

The studies carried out in the Water Survey laboratories have led the investigators to adopt the following equation as representing the complete anaerobic fermentation of materials containing C,H,O,N,S, and any metal ion M with valence "v."[2]

$$C_aH_eO_bN_cS_dM_{ev} + \left(n - \frac{a}{4} - \frac{b}{2} + \frac{7c}{4} + \frac{d}{2} + \frac{3ev}{4}\right) H_2O =$$

$$\left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4} - \frac{5c}{8} + \frac{d}{4} - \frac{9ev}{8}\right) CO_2 + \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3c}{8} - \frac{d}{4} + \frac{ev}{8}\right) CH_4$$

$$+ c\ NH_4HCO_3 + d\ H_2S + eM(HCO_3)v \qquad \text{(Equation 1)}$$

The gas yields and analyses, when corrected for the dissolved, free and bound CO_2 remaining in the mother liquor at the end of the investigation,

check surprisingly well with those indicated by the general reaction. In all cases investigated, the thermodynamic calculations, using free energy data when available and heats of combustion data where free energy data are not available, show these fermentations to take place with the liberation of energy, or, using the Lewis and Randall[7] conventions for expressing energy changes, the ΔH and ΔF values carry a negative sign.

Many of the energy change (ΔQ_1) values reported by Fair and Moore carry a positive sign, or in other words, indicate that the reaction takes place with an absorption of energy. These authors are of the opinion that the true or normal course of the anaerobic fermentation of sewage solids may take place with either the evolution or absorption of energy. They, however, seem to favor the idea that the reaction is endothermic. That is, it takes place with the absorption of energy (expressed by positive values for ΔH_1 and ΔQ_1). As this is contrary to the conclusive observations made by Sierp[15] on the heat generated by digesting sludge, as well as contrary to the opinions of the present writers, those of Wilson and Peterson,[9] Fulmer and Liefson[10], Hill[11] and many others who have conducted fundamental studies on bacteriological degradations, we have thought it advisable to review carefully and critically the data and conclusions drawn. With the exception of the green, chlorophyl-bearing plants there are no biochemical reactions known that take place with an over-all absorption of energy from outside sources. Chlorophyl-bearing plants gather their energy from the sun's rays.

If Fair and Moore's ΔQ_1 values are assumed to be equivalent to ΔH values it is still possible that they might be of opposite sign to ΔF which is the true criterion of energy change. (See Fair and Moore, page 766, also references 7, 10 and 11.)

First, the basic gas data offered by Fair and Moore will be discussed after which attention will be directed to their thermodynamic considerations.

Basic Gas Data

The basic gas data on which this series of articles largely rests (see Table IV, page 768) vary widely within each series. For example, in Series II from 0.90 to 1.26 gms. of gas were obtained per gm. of volatile matter destroyed, and in Series III these same values ran from 1.45 to 1.96. As noted in these data the yields also vary widely from series to series (compare Series II with Series III, both on fresh solids and seeding reported good). In many cases, the gas recoveries are too high to be representative of sewage solids[6] as, for example, in Series III an average of 1.65 gms. of gas were recovered per gm. of volatile matter destroyed. Of all the materials likely to be present in sewage solids, the fats produce the greatest weight of gas per unit of volatile matter destroyed, but even the least oxidized of the common fats, namely, glyceryl tristearate, gives only 1.53 gms. of gas

per gm. decomposed.[6] Our data indicate that the average figure for sewage solids seems to be about 1.2 gms. The excessive values reported in Series III and in other instances suggest the possibility that errors in technique or incorrect assumptions may account for the results reported.

The wide variations noted in the gas recovery data can be attributed to a number of factors. In the first place, no account has been taken of the dissolved gases left in the mother liquor at the end of the digestion. The gain in free and combined CO_2 varies widely. In many cases, the gain amounts to as much as 2 liters of CO_2 per liter of mother liquor. High digestion temperatures give lower CO_2 values. More CO_2 was therefore retained in the 25° C. digestions conducted by Fair and Moore than in the similar digestions conducted at 60° C.

The importance of good inoculation was discussed in one paper by Fair and Moore, but the adequacy of the inoculation used in their present tests may be questioned. Old, worked-out sludge has repeatedly been found to be of limited value as an inoculum. Continuous transfer of part of the old sludge from a previous series to the next series, and then after complete digestion use of a part of this to start a third digestion, has not been found advisable. This practice is probably the cause of the delayed fermentation or marked lag phase noted in the gas data. The rate of gasification curve (Figure 2, page 431) illustrates this point. It is a typical bacteriological growth curve.[12] The sigmoid curve drawn to represent the course of sludge digestion, as measured by gas production, is not typical of similar studies (curves) obtained in this and many other laboratories in cases where good inoculation was possible. A semi-parabolic type of curve more nearly represents the true rate of gas production under optimum conditions. Hatfield,[13] for example, found that 50 per cent of the gas from fresh sewage solids was evolved in the first 24 hours. Likewise Buswell and others[14] recovered 90 per cent of the total gas from sewage solids in 5 to 7 days. These observations illustrate the actual rate of gasification noted in practice when good inoculation is possible. They also illustrate the danger in attempting to apply data from small batch experiments to continuous feeding digestions. The usefulness of the formula (page 433 and page 436) proposed by Fair and Moore is not apparent when one considers that the constants appear to be applicable only for the single batch experiment and are not universally applicable when once evaluated.

Fair and Moore used exceptionally large amounts of inoculum or seeding material in their studies. As noted in Table III, page 592, the ratio of volatile matter in the raw sludge to volatile matter in the seeding sludge ran from 0.84 (Series I) to 2.28 (Series II). The average was 1.61. In other words, every 1.61 parts by weight of material under study was contaminated with 1 part of impurity (old digested sludge). The part played by the large quantity of old sludge, other than that of serving as the inocu-

lum, is open to question. Apparently no attempt was made to apply a correction for the seeding material. In many of the earlier studies carried out by ourselves the amount of inoculum used was appreciable but more recent investigations on the fermentation of pure compounds and cellulosic materials have been made using inoculums which amount to only from 0.1 to 5 per cent of the weight of the material digested. Batch experiments, such as those conducted by Fair and Moore and in which a relatively small amount of material can be digested, have been replaced by fermentations in which a very small amount of inoculum is used and to which a large quantity of material is fed over a long period of time. Some of the results of these studies have been published.[2,3,5,6] Other papers are now being prepared.

Fair and Moore have realized a number of possible sources of error in their studies. One additional source should be added, namely, that involved in the determination of volatile matter in such materials as sewage sludges. The authors do not state the temperature and technique used in determining the loss on ignition (volatile matter) values. The temperature of drying and the initial rate and final temperature utilized in burning the dried solids have much to do with the results obtained. If ignited at temperatures above that of the decomposition of such materials as $CaCO_3$ and the volatilization temperatures of such materials as NaCl, misleading results will be obtained. The best ignition temperature is in the range of 800° C.

Fair and Moore infer that the B. t. u. values given in the first of their series of articles would allow them to conclude that the fuel value of sludges of like types may be expressed by the equation $\Delta Q = CP^n$ where C and n are constants all alike for one kind of sludge. These fuel values, however, as noted in Figure 1, page 243, vary widely from the equation.

Thermodynamic Considerations

In the fourth paper of the series, apparently the equation ($\Delta Q_1 = \Delta Q_2 + \Delta Q_3 - \Delta Q_4$) is not set up in accordance with the Lewis and Randall conventional quantities. Fair and Moore either did not use the equation as set up or else did not use the conventions of Lewis and Randall. This is apparent from the signs obtained in their calculations. For example, in Series I, temp. 25° C., substituting their values with the correct sign, as used by Lewis and Randall, the value obtained is

$$\Delta Q_1 = (-212.0) + (-152.0) - (-465.0) = +101.0 \qquad \text{(Equation 2)}$$

whereas the value should be -101.0 as they show it to be.

The equation should be set up as follows:

$$\Delta Q_1 = \Delta Q_4 - (\Delta Q_2 + \Delta Q_3) \qquad \text{(Equation 3)}$$

Furthermore, we question conclusions based on the sign or magnitude of the quantity ΔQ_1. So many factors have been neglected in its evaluation

that it is not related to either ΔH_1 or ΔF_1, the latter one being a unique thermodynamic quantity whose determination depends on consideration of concentration, heats of solution, de-solution and wetting. If ΔQ_1 were a unique thermodynamic quantity it might be profitable to calculate values for the chemical reactions ensuing in sludge digestion. Since the reaction appears to be a hydrolytic oxidation-reduction (Equation 1)[2] it also seems beside the point to make calculations for other reactions that may explain various mechanisms of anaerobic oxidation, particularly since these equations (those discussed by Neave)[4] were not proposed as explaining the reactions taking place during sludge digestion.

In the case of reactions which appear to require energy when the free energy change of the reaction is calculated at standard state* or at concentrations of 0.1 *N*, it must be remembered that the concentration existing in or about the bacterial cell is unknown. Also this concentration may be and probably is continually decreasing as the fermentation proceeds. Calculations of the free energy of certain reactions at the very dilute concentrations usually existing in fermentations show that the sign of ΔF may change from positive at standard state to negative at the lower concentration.[8]

Fulmer and Liefson[10] have shown $\Delta F°_{298}$ in the alcoholic fermentation of sucrose to vary from -116.6 at standard state to -138 to -143.6 at conditions likely to be obtained in the fermentation. By choosing the proper concentration it would be possible to vary ΔF to produce a wide difference between it and ΔH. Furthermore, ΔF varies with the equilibrium constant which changes greatly with temperature in accordance with the equation:

$$\Delta F = \Delta F° + RT \ln K \qquad \text{(Equation 4)}$$

Various temperatures were used in the experiments of Fair and Moore whereas it is not permissible to apply values obtained for ΔF at 298° to any other temperature. It is also incorrect to assume partial pressures of $^1/_3$ atmosphere for carbon dioxide and $^2/_3$ atmosphere for methane in equations in which the partial pressures of the respective gases are defined by the equation. The actual partial pressures should be used.

Summary

Many of the conclusions and thermodynamic relationships proposed by Fair and Moore are not justifiable in our opinion because:

(1) The gas production data vary too widely among themselves to be used as basic data.

(2) In many cases yields of gas per gm. of volatile matter have been

* "The standard state is defined as the state in which the activity of the substance is unity. Thus, at 25° C. and under 1 atmosphere of pressure, solid glucose, liquid water, gaseous oxygen and a molar solution of the solute (with proper corrections for deviations from a perfect solution) are in standard state." Wilson and Peterson.[9]

reported and used as basic data, which are far in excess of observed or calculated maximum yields.

(3) No corrections have been made for the gain in dissolved free and bound CO_2 in the mother liquors.

(4) No corrections have been made for the large amounts of inoculum solids used.

(5) The discussion of rate of gasification is not based on representative rate data. The lag phase noted was undoubtedly due to poor inoculation.

(6) Sampling and analytical errors involved in sewage studies are admittedly large. Variations within the known limits of these errors are obviously not significant.

(7) If the ΔQ_1 values associated with the experiments in which excessive volumes of gas were recovered are disregarded, and those that are within experimental error are not considered, all the remaining values are found to possess a negative sign, that is, the reaction takes place with an evolution of heat.

(8) The conclusion that the bacteriological degradation of sewage solids may take place with an absorption of energy (endothermic) is contrary to the mass of data collected by previous workers in various fields using pure compounds which definitely show that the over-all change must be accompanied by a decrease in free energy.

(9) Careful inspection as to the mode of obtaining the ΔQ_1 value shows that it does not represent a specific thermodynamic quantity.

(10) Conclusions built around a mathematical consideration of the second law of thermodynamics and its applicability to the question under discussion are in error because sludge digestion reactions are not reversible.

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Authors' Reply

Discussion by A. M. Buswell, *et al.*, of Fair and Moore's Articles on "Heat and Energy Relations in the Digestion of Sewage Solids"

BY GORDON M. FAIR AND EDWARD W. MOORE

A collection of papers condensed in statement, yet covering a wide field of interest, must necessarily leave some things unsaid and many things insufficiently treated. This is true of the authors' papers,[1] which were made public in their present brief and preliminary form chiefly for the purpose of directing the attention of other workers to the methods of study and analysis that the authors were finding useful in their attack upon the problem of sludge digestion. It was their intention to expand at some future date upon the various subjects reported and to submit the results of further experiments that are now under way. In the meantime, they have welcomed reactions to their ideas from other workers and have stood ready to assist so far as they could in ironing out any difficulties which readers may have had in interpreting correctly the presentation of the subject matter covered in their papers.

The questions raised in the discussion of the authors' papers by Althausen, Boruff, Buswell and Symons give the authors an opportunity to supplement at this time some of the explanations of their work. They will do so at the hand of the comments made by the Illinois workers whose fundamental studies in the bio-chemistry of sewage treatment are of greatest interest.

The questions raised by Althausen, Boruff, Buswell and Symons are so varied that it has seemed best to the authors to answer them more or less in the order in which they occur in the discussion rather than attempting to classify them for reply.

If the authors interpret the introductory paragraph of the Illinois workers' comments correctly, the latter read into the authors' papers the claim that "bacteria and other organisms devoid of chlorophyll or similar substances and in the absence of sunlight can catalyze reactions which yield products with greater energy content than the starting materials...." No such claim has been made. What the authors have stated is that under certain circumstances the heat-producing power—not the free-energy content or work-producing power—of the products of digestion can become greater by virtue of the absorption of heat from the surroundings. This contention has its analogy in the heat-producing power of a gram of water becoming greater when the water is converted into steam by heat from the surroundings. It is an endothermic reaction in which heat only is absorbed from the surroundings as distinguished from a photosynthetic reaction, in which free energy, or work-producing power, is absorbed from sunlight and

converted into the free energy of the substance of the plant. In the endothermic reaction the heat absorbed must remain as latent heat, or heat of combustion, a low form of energy which is never available as free energy. It follows that it would be as incorrect to read into the authors' papers the statement quoted at the head of this paragraph as it would be to read into the Illinois workers' comments the statement that no endothermic reaction can occur in the absence of photosynthesis. In passing it may be interesting to note that the authors' experimental findings that sludge-digestion can lead to products that have a higher combustion value than the original material is supported on experimental evidence by Bach,[2] who is the only other worker, to the knowledge of the authors, who so far has reported a heat balance for digesting sewage solids.*

In view of the mass of evidence to the contrary, he would be foolhardy indeed who would claim that bacteria can effect reactions of the photosynthetic type and that they can do this in the dark into the bargain. No reaction can take place in which ΔF (the so-called free energy) is positive, *i. e.*, in which free energy is absorbed, unless that energy is supplied directly as chemical, electrical or actinic energy. Heat cannot be used. In a spontaneous endothermic reaction ΔF must be negative; ΔH (the change in heat content) can carry either a negative or a positive sign but must be greater than ΔF. The heat absorbed is then $\Delta H - \Delta F$ (see Lewis and Randall, p. 169 et seq.), assuming that the reaction runs reversibly. It is this heat alone that can account for a positive ΔQ_1 (gain in heat of combustion). The longer the time taken for the process, the nearer does it approach reversibility and the greater is the fraction of this potential absorption actually obtained. Combustion is an irreversible process, in which none of this potential absorption is realized. The authors restate, therefore, that—unless future work shows that their experiments, as well as Bach's experiments, cannot be duplicated or that their work, as well as Bach's work, involved an error in technique as yet unrecognized by them, as well as by Bach,[2] in spite of diligent search before publication of results—the digestion of sewage solids may, on striking an over-all heat balance, yield more heat (not free energy) than indicated by the combustion of the starting materials. Incidentally, Buswell and Neave[3] seem to have no quarrel with the concept of a digestion reaction that absorbs heat and hence is endothermic, and they agree that this heat comes from the surroundings. It must be emphasized in this connection that in an over-all heat balance, or even in a free energy balance for an over-all reaction, we are not concerned with mechanisms of reaction or occurrences at the wall of the bacterial cell. The authors have not suggested that their ΔQ_1 values can be "assumed to be equivalent to ΔH values." They do state that ΔQ_1 is a

* EDITOR'S NOTE: See, however, the article by Keefer and Kratz in this issue, page 3.

measure of the heat absorbed from the surroundings and approaches $\Delta H - \Delta F$ as the reaction becomes more reversible.

Basic Gas Data

Although the basic gas data, as the authors have pointed out (p. 599), are capable of some improvement, they are believed to be sufficiently reliable, especially when considered in the light of the authors' previous experience and that of other workers,[5-21] to support whatever deductions the authors have made for the purpose of orienting their continuing attack on the problem. In comparing results within each series and for different series, the reader must bear in mind that within each series digestion was carried on at different temperatures (except for Series VII) and with different seeding residues (after Series I); furthermore, that each series represents either a single random day's catch of fresh sewage solids at Fitchburg, Mass., or of activated solids at the Lawrence Experiment Station. The substantial harmony of experimental results obtained in studying the batch digestion of sewage solids under conditions such as those necessary in the authors' studies continues to be a source of pleasant rather than unpleasant surprise to them. The average gas yield (1.28 grams per gram of volatile matter destroyed) observed by the authors (page 770), for example, although including values to which the Illinois workers take exception, is almost exactly the same as that suggested by Buswell and Boruff.[22]

It is true that no account was taken of the dissolved gases (mainly CO_2) remaining in the mother liquor. It is also granted that generally more CO_2 will be retained at 25° C. than at 60° C. It must be pointed out, however, that the methane, which parenthetically is the only important gaseous constituent entering into the heat balance, cannot be retained in the mother liquor in significantly different amounts either with change in temperature or condition of the mother liquor. Unlike CO_2, the only methane retained by the mother liquor is that held in solution. According to Seidell,[23] the solubility of methane at a pressure of 1 atmosphere is 30 cc. per liter at 25° C., and 19.5 cc. at 60° C., a difference of 10.5 cc. per liter. This amount is too small to be significant in an experiment which produces, under a partial pressure of about $^2/_3$ atmosphere, 10 to 20 liters of methane per liter of digesting mixture. If, therefore, the variability of the basic gas data could be accounted for by reason of gas retention within the mother liquor, as suggested by the Illinois observers, two requirements would have to obtain: (1) a large variability in the percentage methane and CO_2 content of the total volume of gas produced during digestion at different temperatures; (2) a relative constancy of the yield of methane per gram of volatile matter destroyed during digestion at different temperatures. Examinations of the authors results show that neither requirement was fulfilled in their experiments. The composition of the total gas col-

lected was, in every case, 67 per cent methane and 33 per cent CO_2 within one or two per cent, and the variation in yield of methane, as shown in the following summary for Series III, was almost parallel to that of CO_2 and hence also to total gas production.

Temperature ° C.	Gas Production Grams per Gram Volatile Matter Destroyed		
	Methane	Carbon Dioxide	Total
25	0.625 (43%)*	0.825 (57%)	1.45
30	0.620 (42%)	0.850 (58%)	1.47
35	0.620 (42%)	0.850 (58%)	1.47
40	0.859 (44%)	1.100 (56%)	1.96
45	0.775 (42%)	1.065 (58%)	1.84
50	0.726 (43%)	0.965 (57%)	1.69

*NOTE: 43% by weight is equal to 67% by volume.

In regard to "the adequacy of the inoculation used in their present tests," the authors should like to refer to the recent paper by Heukelekian[21] in THIS JOURNAL. This authority shows that within reasonable limits the age of sludge has little to do with its seeding value. Storage of thermophilic sludge up to 3 months did not deteriorate its seeding value. Moreover, the seeding value of the sludge increased tremendously up to the point where digestion was nearly complete (90 to 95% of total gas evolved). The value decreased slightly beyond this point, and the sludge was but little less effective as the limit of gas production was approached. In the light of this as well as earlier work by Heukelekian,[11] the authors feel that there can have been no appreciable loss in value of the seeding sludges because of their passage through several digestions during which accretion of new sludge took place and between which there were no long storage periods. Incidentally, the reference to the discussion of seeding in a previous paper by Fair and Moore is unknown to the authors.

As to the method of seeding chosen by the authors probably being "the cause of the delayed fermentation or marked lag phase, noted in the gas data," the authors claim that such a first stage must be part of every curve of gas evolution during batch digestion, unless we learn to produce instantaneous and perfect seeding. This, as indicated later, is a physical impossibility. In this connection it might be well to differentiate between the term "inoculation" used by the Illinois workers and the term "seeding" used by the authors. According to the authors' understanding, seeding implies at least three functions: (1) inoculating the raw sludge with the bacteria (and other organisms if necessary) requisite for normal digestion; (2) supplying to the raw sludge the ferments required to initiate digestion; (3) providing an adequate background of buffering substances requisite for normal digestion. There are other possible advantages of seeding which are probably of minor moment. Heukelekian,[11] in discussing the major functions of "seeding solids," states in particular that "for seeding pur-

poses that sludge is best which has attained its complete decomposition, but has not been stored too long." Inoculation implies to the authors the first of the three important functions of seeding or, at most, the first and the second, and the thought suggests itself that regional differences in the mineral content of sewages in the Middle West and in the East may make it necessary for Eastern workers to call upon the buffering power of seeding sludge to a greater extent than their middle western colleagues. Instantaneous and perfect seeding would demand (1) the provision of as many able-bodied bacteria (or other organisms) as the sludge could support; (2) provision of sufficient enzymes to prepare instantly as much of the organic matter as the maximum bacterial population could consume; (3) perfect and instantaneous mixing of bacteria, enzymes and sludge; (4) perfect and instantaneous buffering. Obviously such an ideal state cannot be reached, and a "first stage" of digestion becomes a necessary occurrence. There results an S-shaped curve which, as pointed out by the Illinois workers as well as by the authors (p. 440), is a curve also associated with bacterial growth.

With reference to the authors' formulation of the course of digestion, Althausen, Boruff, Buswell and Symons state, "The sigmoid curve drawn to represent the course of sludge digestion, as measured by gas production, is not typical of similar studies (curves) obtained in this and many other laboratories in cases where good inoculation was possible. A semi-parabolic type of curve more nearly represents the true rate of gas production under optimum conditions." Since these two statements are not supported by references to their own work or that of other laboratories, the authors, without going outside the confines of THIS JOURNAL, would like to call attention to eighteen papers,[4-21] constituting every research paper so far published in THIS JOURNAL dealing with batch digestion experiments, every one of which shows that the S-shaped curve of total gas production, or its differential form, the bell-shaped curve of rate of gas production, is typical of such studies. No semi-parabolic type of curve can satisfy a process such as sludge gasification, even under optimum conditions.

The Illinois workers do not state whether the semi-parabolic type of curve, which is to represent more nearly than the S-shaped curve total gas production versus time, is concave to the time axis or to the gas-yield axis. If we assume the former, this being the only reasonable assumption if we are thinking in terms of batch experiments and the authors' work concerns itself only with studies of this type, the equation of the semi-parabolic curve may be given as follows (using the symbols* employed in the authors' papers):

$$G = Ct^k \qquad (a)$$

or

$$\log G = k \log t + \log C \qquad (b)$$

* G = amount of gas produced in time t; k and C = constants.

In these equations k must be less than 1 but greater than 0, in order to create a semi-parabolic curve concave to the time axis. The slope of this curve is:

$$\frac{dG}{dt} = kCt^{k-1} \qquad (c)$$

where $\frac{dG}{dt}$ is the rate of gas production and $(k - 1)$ is a negative quantity. To render the exponent of t positive, we may write:

$$\frac{dG}{dt} = \frac{kC}{t^{1-k}} \qquad (d)$$

Equations (a) to (d) imply the following:

(1) At time 0, $G = 0$ (correct)
(2) At time ∞, $G = \infty$ (incorrect)
(3) At time 0, $\frac{dG}{dt} = \infty$ (incorrect)
(4) At time ∞, $\frac{dG}{dt} = 0$ (correct)

In words: to satisfy a semi-parabolic type of equation, gasification must begin at an infinite rate, and approach an infinite quantity providing sufficient time is allotted for digestion. Obviously both of these conditions are impossible of attainment. The authors must conclude, therefore, that the use of the term "semi-parabolic" was unfortunate and that what the Illinois workers have in mind is a curve representative of a so-called "unimolecular reaction." While such a curve has some resemblance to a semi-parabola, it is by no means akin to it mathematically. The unimolecular equation is given in the authors' papers (page 432) as follows

$$\log (L - G) = -kt + C \qquad (e)$$

For $(t = 0)$, $(G = 0)$, C can be evaluated as $\log L$, and equation e becomes:

$$\log \frac{L - G}{L} = -kt \qquad (f)$$

In its differential form, this equation may be written:

$$\frac{d(L - G)}{dt} = -k(L - G) \qquad (g)$$

or

$$\frac{dG}{dt} = k(L - G) \qquad (h)$$

Equations (e) to (h) imply the following for a total potential gas production L:

(1) At time 0, $G = 0$ (correct)
(2) At time ∞, $G = L$ (correct)
(3) At time 0, $\frac{dG}{dt} = kL$ (theoretically possible)
(4) At time ∞, $\frac{dG}{dt} = 0$ (correct)

In words: to satisfy a unimolecular formulation, gasification must begin at a rate kL which diminishes constantly as gas is evolved [rate $= k(L - G)$] until it becomes zero as the limit of gas production (L) is reached. As previously indicated, however, any departure from perfect instantaneous seeding affects the applicability of this formulation which is merely a special case (perfect instantaneous seeding) of the authors' general formulation of sludge digestion as an autocatalytic or two-stage curve. It should be noted that the autocatalytic equation (page 433)

$$t = \frac{1}{k_1 + k_2 L} \log_e \frac{L(k_2 G + k_1)}{k_1(L - G)} \qquad (i)$$

becomes unimolecular when k_2, the first-stage constant of digestion, is 0; in other words, when the breaking in of the sludge becomes unnecessary by virtue of perfect instantaneous seeding. In a similar way the authors' two-stage formulation (pages 436–437):

$$\text{First stage:} \quad \log G = K_1 t + \log C_1 \qquad (j)$$

$$\text{Second stage:} \quad \log (L - G) = -K_2 t + \log C_2 \qquad (k)$$

becomes unimolecular when K_1, the first-stage digestion constant, is 0. When very high rates of gasification are experienced, such as those reported by Hatfield, *et al.*[24] for the industrial sewage of Decatur, it becomes necessary to determine the time coördinates of the digestion curve at hourly intervals (or less); otherwise the first stage of the curve (about 50% digestion) will appear as a straight line rather than as the upward swing of an S-shaped curve. Interpretation of plots in which this fact is not taken into account might then lead to the assumption that the progress of digestion can be represented by a unimolecular equation.

In view of these considerations the authors wish to restate that their mathematical formulation of the course of sludge digestion, as measured by gasification, bears promise of usefulness as a convenient method of representing, comparing and correlating experimental data of the batch type, but that this formulation is not an expression of opinion regarding the probable mechanism of the reaction (page 440). In this connection the authors are unaware of having attempted in their papers to "apply data from small batch experiments to continuous feeding digestions." It has been the purpose of the studies, so far reported, to formulate the course of

digestion of individual portions of sludge and to enlist the coöperation of other workers in establishing both the magnitude and variability of the parameters of digestion by more extensive as well as more refined work (page 599). There was no thought of the constants so far reported by the authors being "universally applicable."

The amounts of seeding material employed by the authors were purposely made substantial in order that the raw solids should be backed up (not "contaminated") by an adequate amount of good seeding material (not "impurity"). A study of those references at the end of this discussion which deal with batch digestion will show that a seeding ratio of two parts of raw volatile matter to one of digested has commonly been employed in order to attain good seeding. Particular attention is called to the original paper of Rudolfs[25] on thermophilic digestion and to the second paper of the series in which Heukelekian[10] finds that reduction of the seeding material below this 2 : 1 ratio greatly increases the time required for digestion. Rudolfs and Lacy,[14] furthermore, find that for proper seeding a 2 : 1 ratio is required and that a 3 : 1 ratio produces inferior digestion as reflected both by gas production and by time of digestion.

With respect to corrections for the seeding material, the authors claim the following: Gasification being negligible in well-digested sludge, the use of seeding material cannot affect the gas yields except to a negligible extent at the beginning of the experiment. Hence it has no bearing upon the formulation of gas production. Its fuel value, furthermore, is included both in that of the initial mixture and in that of the final product. Hence no correction need be applied to the heat balance.

It has been stated in the papers (page 759) that determinations of volatile matter and total solids were made in duplicate in order to obviate errors from this source. These tests were carried on according to standard procedures, the solids being dried at 105° C. in an electric oven and the volatile matter being ignited in an electric muffle furnace at a temperature close to 675° C. The latter temperature is below that suggested by the Illinois workers and is well below the temperature of decomposition of $CaCO_3$ and the volatilization temperature of NaCl.

The Illinois workers call attention to the fact that the fuel values of the authors' sludges vary widely from the equation given in the first of the authors' series of papers. That this is to be expected was noted by the authors in the paper in question (page 245–246). The relationship proposed is clearly stated to be an empirical one devised primarily for the purpose of approximating within about ±12 per cent (pages 266) the fuel value of sewage solids for which only the volatile-matter content is known. It was also suggested that variation of the factors C and n might be of assistance in interpreting the difference in behavior of sewage solids. The authors believe that both functions are worth considering.

Thermodynamic Considerations

As pointed out by Althausen, Boruff, Buswell and Symons the equation $\Delta Q_1 = \Delta Q_2 + \Delta Q_3 - \Delta Q_4$ is not set up in accordance with the Lewis and Randall convention. Rather than introduce, into that portion of the paper dealing with the practical evaluation of data on heat of combustion, a convention which it was thought might prove confusing to engineers, it was decided to set up the equation in such form that the heats of combustion might be taken with a positive sign, rather than a negative sign, as the Lewis and Randall convention demands. Furthermore, the equation is so set up that the sign of ΔQ_1 is positive when the system absorbs heat and negative when heat is lost. This is the dominant aspect of the problem studied by the authors. The same approach, that of taking heat of combustion as positive, is employed by Bach.[2] The conventions of science, it seems to the authors, should be sufficiently flexible to facilitate, not obstruct, ease of understanding in any given case.

Some of the questions relating to the authors' thermodynamic reasoning may be disposed of at once by the observation that in order to determine ΔH and ΔF for a reaction such as $A + B = C + D$, in which all the reactants and products are accounted for, it is only necessary to know the states in which A, B, C and D are found. We need not concern ourselves with the mechanism by which the process is accomplished.

In the case of the fatty acid reactions discussed in the paper, a balance has been struck for a concentration of the fatty acid meant to approximate that which might be encountered in sewage sludge, plus water, yielding CO_2 and CH_4 at the average pressures found in the digestion process (page 763). A knowledge of the concentration in or about the bacterial cell is not necessary, and any heat or energy balances struck on the basis of this concentration cannot be of use in the practical evaluation of the heat or energy to be derived from sewage solids. They can be useful only in studying the heat relationships of the cell itself. The ΔH and ΔF of the reaction must be the same whether the reaction proceeds by direct combination at the concentrations prevailing in the solution, or by diffusion of reactants into the cell and diffusion of the products outward. Otherwise perpetual motion might be established. This is equivalent to saying that the ΔH and ΔF of the reaction $C + O_2 = CO_2$ must be the same whether the reaction proceeds in one step, as above, or in two steps, through the intermediate formation of CO.

With reference to the remaining points of discussion of thermodynamic import, ΔQ_1 is not intended to be a "unique thermodynamic quantity." It is a purely empirical measure of the difference in heats of combustion of the products and the reactants, based on measurements of those heats of combustion. If the heats of combustion of the reactants are less than those of

the products, the excess of heat must have been derived from the surroundings, as shown for the illustrative oxidation of carbon in the paper (page 760). There is no other source that it could come from. As shown by the authors (page 756), ΔQ_1 as a measure of the heat actually absorbed is in error by the difference in heats of solution of the undigested and digested materials, but it is not believed that it can be proved that this difference is of sufficient magnitude to reverse the sign of ΔQ_1 in any of the experiments.

The purpose of calculating the heat absorbed ($\Delta H - \Delta F$) for the proposed anaerobic oxidation reactions, including those "not proposed to explain sludge digestion," was not, as the discussion seems to assume, to find what the value of ΔQ_1 should be, but merely to indicate that these reactions are of a type that might yield a positive ΔQ_1. The heat change obtained in a practical experiment would, of course, vary between ΔH (complete irreversibility) and $\Delta H - \Delta F$ (complete reversibility). To quote Lewis and Randall (pages 169–170): "In the specific reaction which we have been considering, $\Delta H = 22{,}730$ cal. If a mol of lead reacts irreversibly with mercurous chloride, as in the calorimeter, 22,730 cal. are given up. But we have seen that $\Delta F = -24{,}720$, so that in the reversible, isothermal process, the work done is greater than the heat of reaction. Therefore when this galvanic cell operates reversibly in a thermostat, heat is not given to but taken from the thermostat to the extent of 1990 cal. for each mol of lead." The same situation holds for anaerobic oxidations, in which, as the authors have shown, the work done is much greater than the heat of reaction. Obviously this does not mean, however, that the experimental ΔQ_1 should conform to the theoretical $\Delta H - \Delta F$. Bacteria apparently are not perfectly reversible engines, nor do we know the degree of their reversibility. A perfectly irreversible process is instantaneous; a perfectly reversible one requires infinite time; and sludge digestion is neither.

It is granted that the concentration of the reacting medium, such as the solution of fatty acid, changes as the reaction proceeds, and that ΔF therefore also changes. In order to establish the validity of this criticism of what was merely intended to be an approximate evaluation of ΔF requires that the magnitude of the change so produced be evaluated. Let us, for example, consider the ΔF_{298} for the reaction:

$$2CH_3[CH_2]_2COOH + 2H_2O = 3CO_2 + 5CH_4,$$

at a concentration of acid of 0.1 N, which is found to be -23 kg. cal. Assuming the pressures of the gases (and therefore their activities) to remain relatively constant, the change in ΔF_{298} will be equal to twice the change in F_{298} for propionic acid. If the concentration is reduced to 0.01 N, a tenfold change meaning that 90 per cent of the material has been consumed, the change in F_{298} as derived from the relation $F'_{298} = F_{298} - RT \log_e \frac{c}{c'}$ is

$-RT \log_e \frac{c}{c'}$ or $-2.3\,RT \log \frac{c}{c'}$. Hence for $\frac{c}{c'} = 10, -2.3\,RT \log \frac{c}{c'} = 1.365$ kg. cal. The change, therefore, is 1.365 kg. cal., and the change in ΔF_{298} is some 2.7 kg. cal. after 90 per cent of the material has been consumed. The error produced by taking $\Delta F_{298} = -23$ kg. cal. per mol as the work done during this change is only one-half this amount of 2.7 kg. cal.

The same reasoning applies to the change in ΔF produced by change in the partial pressures of methane and CO_2, the equation being $F_{298}' = F_{298} - RT \log_e \frac{p}{p'}$. But in this case the changes in partial pressure are by no means as large as tenfold. The partial pressure of CO_2 varies from about 0.5 to 0.2 atmosphere, and that of methane from 0.3 to 0.8 atmosphere. The errors thus introduced are correspondingly smaller.

In a system in which concentrations and pressures change, the determination of ΔF at any one stage in the process is of no service in computing the work that the process can do. We are not interested in the ΔF at any one instant, but in an approximation of what may be termed an over-all average ΔF for the entire process, which will be a measure of the work obtainable from the process. In such a case, the use of approximate concentrations and average pressures would seem to be legitimate. We must only make sure that the errors thus introduced are not so large as to render the value useless for its intended purpose.

With respect to the variation of ΔF in the fermentation of sucrose, the authors would like to point out that according to the equation: Heat absorbed $= \Delta H - \Delta F$, the lower ΔF is for a given ΔH, the more heat is absorbed and the more likelihood there is of a positive ΔQ_1. Also, the reaction $\Delta F = \Delta F^\circ + RT \log_e K$ as given in the discussion of the Illinois workers is not identical with the equation given by Lewis and Randall (pages 293–294). For a reaction:

$$lL + mM \ldots = qQ + rR,$$

the relation between ΔF°, the free energy change when each substance is in its standard state, and ΔF, the free energy change when the substances are in any other state (which we may call state B) is as follows:

$$\Delta F = \Delta F^\circ + RT \log_e \frac{A_Q^q A_R^r}{A_L^l A_M^m}$$

where AQ, etc., are the activities of the substances in state B. If state B is a state of equilibrium, so that

$$\frac{A_Q^q A_R^r}{A_L^l A_M^m} = K \text{ (the equilibrium constant)},$$

then $\Delta F = 0$. Hence, the correct equation is $\Delta F^\circ = -RT \log_e K$. This equation is of service only in calculating the standard free energy at a

given temperature from the equilibrium constant at that temperature, or *vice versa*. No application of values of ΔF_{298} has been made by the authors to other temperatures. The sole purpose of discussing ΔF values was, as before noted, to show that anaerobic oxidations are heat absorbing reactions, and as such, may yield positive values of ΔQ_l as observed in our experiments. Incidentally, if the equilibrium constants of the reactions of sludge digestion increase with temperature, corresponding to a more rapid evolution of the gas at higher temperatures, then according to the equation $\Delta F^\circ = -RT \log_e K$, ΔF° and hence also ΔF would be larger negative quantities. This would not tend to decrease the value of $\Delta H - \Delta F$. With reference to the fact that positive values of ΔQ_l are associated with high yields of gas per unit weight of volatile matter destroyed, this would obviously appear to be a *sine qua non* which lends weight to the evidence, rather than being a coincident error of independent "heat of combustion" and "volatile matter" determinations.

It stands to reason that a strict evaluation of so complicated a process as sludge digestion cannot be made at the present time. Present uncertainty, however, should not deter workers from trying to trace roughly the outline of the picture so far rendered visible—"if for no other reason than to point out the way for future investigations" (page 601).

In speaking of energy, care should evidently be taken to define as clearly as possible the terms used. Chlorophyllaceous organisms can absorb free energy from sunlight and store it as the free energy of the compounds of the plant. For the photosynthesis of the plant, ΔF is a positive quantity. There are, however, many reactions which proceed spontaneously, ΔF being a negative quantity, but which absorb heat, *i. e.*, ΔH, the heat of reaction, minus ΔF, the work-producing power of the reaction, is a positive quantity. Reactions of this type are discussed by Lewis and Randall (pages 169–171). They are endothermic, *i. e.*, they absorb heat, and there is no evidence that chlorophyll and sunlight are required for their operation. Similarly, Buswell and Neave,[3] in speaking of their hydrolytic oxidation reactions, state "if heats of formation are merely substituted in the equation as it stands, the reaction is endothermic . . . the subsequent dissolution of methane and decomposition of H_2CO_3 are extracellular reactions for which heat energy has to be supplied from the surroundings." The quantity derived by the use of heats of formation is ΔH, and Buswell agrees that it is positive; *i. e.*, the reaction is endothermic which means that heat is absorbed. Lewis and Randall (pages 169–171) show that ΔH measures the heat change of the reaction only when the reaction runs irreversibly, *i. e.*, when no use is made of the work-producing power or free energy, ΔF, of the reaction. When this work-producing power is utilized at 100% efficiency, or in other words reversibly, the heat change of the reaction is $\Delta H - \Delta F$. We know that bacteria utilize the work-producing power,

ΔF, of the reaction, not the heat change, ΔH. They are little chemical engines, not little steam boilers. Since they do not utilize free energy at 100% efficiency, the change in heat must lie between ΔH and $\Delta H - \Delta F$. In any particular case, however, the heat change is not represented by ΔH, because the bacteria utilize the work-producing power of the reaction, which for anaerobic oxidations seems to be greater than the heat-producing power, and this work is used to pump heat into the reaction mixture for such things as the "dissolution of methane and decomposition of H_2CO_3."

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Chemical Sewage Purification at Palo Alto*

Regeneration of Spent Coagulant Effects Complete Sewage Treatment

BY RALPH A. STEVENSON

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Very little interest has been manifested during the past few years in the field of chemical sewage purification and today sanitarians generally think of it in terms of former practice. In the light of present-day developments and knowledge of coagulation and sedimentation, the older attempts appear somewhat crude. Lime was usually the coagulant, although alumino ferric, A. B. C., and other similar chemicals were tried. The bulky sludge resulting from the usual dose of one ton of lime per million gallons was pressed in crude hand-operated filter presses and was subsequently turned into the ground. The effluent of some of these plants was remarkably clear as it left the plant, but soon became foul. The caustic treatment must have put into solution a considerable amount of organic matter which would decompose when the causticity was neutralized by absorption of carbon dioxide.

The argument for chemical purification was then, and is today, ease and positiveness of control, small simple structures and low capital investment.

Many changes have taken place in the water purification field and we now realize the importance of proper mixing of chemicals and we have a better understanding of sedimentation basin design and the important part played by the inlet and outlet arrangements.

An average sewage will require from 3 to 4 grains of ferric chloride per gallon to completely remove the suspended matter. The use of 4 grains per gallon results in the formation of 376 pounds of ferric hydroxide per million gallons of sewage. To get the greatest benefit from this amount of chemical, the precipitated sludge would have to be disposed of with the sewage solids removed, and we have reason to believe that this amount of iron would seriously interfere with digestion.

We undertook the study of chemical sewage purification because we believed we had discovered a basic reaction which would allow the use of the necessary large amount of coagulant without the disadvantage of having to dispose of the resulting sludge.

We have found it possible to regenerate a spent coagulant such as would result from the use of ferric chloride by treating the resulting sludge with

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chlorine in amounts of from 10 to 30 per cent of the weight of dry solids present. The resulting coagulant quickly forms a voluminous floc which settles rapidly, and if organic matter is present a chloramine substance is formed that has high bactericidal properties. Under certain conditions this cycle can be repeated indefinitely. With sewage, the life of the sludge depends on the amount of organic matter carried down each time by the floc. This is due to the tendency of the organic matter to decrease the

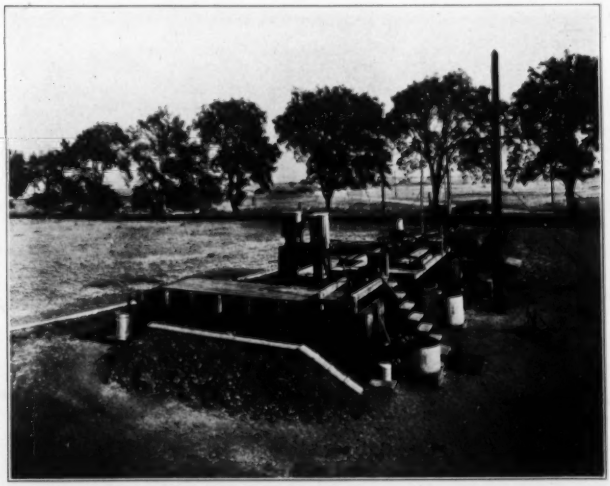

FIG. 1.—Experimental Plant at Palo Alto for Chemical Precipitation of Sewage.

specific gravity of the sludge. Our experience has been that the floc becomes too light for rapid settling after about 50 cycles of regeneration.

In July, 1932, we placed in operation an experimental plant at Palo Alto for the purpose of developing a process based on the re-use of a coagulant. (Figure 1.) The sewage used is entirely domestic except for the usual wastes from garages, laundries and cleaning plants. It has an average B. O. D. of 255 parts per million and 250 parts per million suspended solids. The sewage is screened through a $^1/_2$-inch bar screen and grit is fairly well removed by the orifice box used to measure the plant influent. The plant consists of the following units, the depth of sewage in all of which is 5 feet.

1. Primary clarifier, 17 ft. 6 in. long, 6 ft. wide, 6 ft. deep. Retention period 2 hours 30 minutes. Overflow rate 345 gallons per sq. ft. per day.
2. Two mixing tanks in series, each 4 ft. in diameter.
3. Secondary clarifier, 12 ft. long, 6 ft. wide, 6 ft. deep. Retention period 1 hour 30 minutes. Overflow rate 504 gallons per sq. ft. per day.
4. Two mixing tanks in series, each 4 ft. in diameter.
5. Final clarifier 22 ft. long, 6 ft. wide, 6 ft. deep. Retention period 3 hours. Overflow rate 260 gallons per sq. ft. per day.

The basins are equipped with inlet and outlet baffles fashioned after the remarkably successful design by Prof. Chas. Gilman Hyde for the Sacramento water purification plant. Operation is on a 24-hour basis

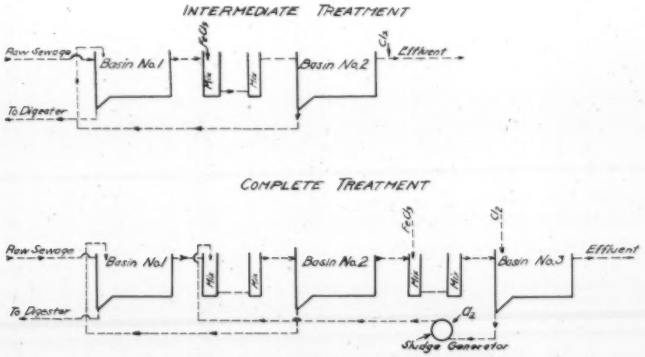

FIG. 2.—Flow Sheet of Chlorinated Sludge Process.

at the rate of 36,000 gallons per day. We intend to increase this rate to determine the ultimate capacity.

The operation to date has been varied over short periods to determine the most economic disposition of the coagulants. Two combinations of treatment have given good results so far and others will be tried. (Figure 2.) One type of treatment is as follows.

For the first 24 hours, 4 grains of $FeCl_3$ per gallon were added to the last stage of mixing for the purpose of building up a volume of sludge in the final clarifier. The ferric chloride was then decreased to 0.75 grain per gallon and regeneration of the sludge commenced. Ten per cent of the amount of spent sludge going to the generator was added to the first mixing tanks to weight down a portion of the suspended solids passing the primary clarifier. This sludge was removed from the second clarifier

and added to the incoming raw sewage. The effluent of the secondary clarifier was then coagulated with the regenerated sludge plus 0.75 grain per gallon of ferric chloride. From 250 to 400 pounds of chlorine per million gallons was required to regenerate the sludge and completely satisfy the chlorine demand of the final effluent. This treatment resulted in a clear sterile effluent and gave as high as 96 per cent reduction in B. O. D. At the end of a two weeks run the sludge, which had been augmented by the addition of 0.75 grains per gallon of fresh ferric chloride, had decreased in specific gravity due to the accumulated organic matter so that some floc was carried through the clarifier and the run was then discontinued.

The next run was planned with the intention of removing more of the suspended organic matter in the first two clarifiers so that the floc in the final stage of coagulation would have less organic matter to remove and would therefore have a longer life. The run was begun with the addition of 1 grain per gallon ferric chloride to the first mixing tank and for the first 24 hours, 4 grains ferric chloride to the final mixers. At the end of this period, regeneration of this sludge was begun and the ferric chloride discontinued except for the 1 grain per gallon dose to the first mixer. The sludge from this application was removed from the second basin and added to the incoming raw sewage. The effluent of the second basin contained remarkably little suspended matter and the 30 minute chlorine demand averaged 8 parts per million. This was coagulated with chlorinated sludge, producing a total removal of suspended matter. An over-all reduction of 95 per cent of the B. O. D. was obtained. After about 50 generations of the sludge, it became too light for rapid settlement and the final stage of purification was discontinued.

The results obtained by the addition of 1 grain per gallon ferric chloride between two stages of settling were so favorable that it was decided to concentrate our activities on this type of treatment for a time. Operation was therefore changed to the following schedule:

One grain per gallon ferric chloride is added to the first mixing tank, the resulting sludge is returned to the incoming raw sewage and the final effluent from the second basin is chlorinated. An over-all reduction of 85 per cent in suspended solids and 75 per cent of B. O. D. is obtained. The effluent is opalescent but quite free from visible particles and odor.

This intermediate treatment requires 2 clarifiers and 2 mixing tanks and the application of ferric chloride and chlorine could be made practically automatic so that constant attendance would not be required. The addition of 142.5 pounds ferric chloride and 80 pounds chlorine per million gallons would make a very cheap and fool-proof process for this degree of treatment. The cost of constructing the simple basins required should also be quite reasonable.

We are about to begin a combination of treatment which we believe will be the ultimate so far as the present experimental plant is concerned. In this set up the ferric chloride will be added to the last stage of mixing, all of the sludge resulting from its use will be regenerated and applied to the first mixing tank. The sludge from the second basin will be returned to the incoming raw sewage, and the final effluent will be chlorinated. In this way a fresh heavy sludge which requires the least amount of chlorine for its regeneration will always be had and two stages of coagulation will be possible from one application of ferric chloride. Our experiments indicate that it will be possible with this type of treatment to effect a removal of 95 per cent of the suspended solids, complete removal of bacteria and at least a 95 per cent reduction in B. O. D. Indications are that this treatment will require 250 pounds of chlorine and 200 pounds anhydrous ferric chloride per million gallons of sewage which, at the present market price, would make the cost of chemicals for a 5 million gallon plant $11.25 per million gallons.

The laboratory work in connection with our experiments has been done at Stanford University through the kind coöperation of Prof. Paul Beard. Special attention has been given those tests which would indicate the stability of the final effluent. Samples containing free chlorine have been neutralized and seeded with filtered raw sewage and all tests have been made in accordance with the standard methods of the A. P. H. A.

We have not as yet had the opportunity to study the effect of ferric hydroxide on the digestion of raw sludge, but there is no reason to believe that the 94 pounds of hydroxide resulting from the use of one million grains of ferric chloride would exert a deleterious effect on the digestion of the 1000 to 2000 pounds of sludge ordinarily present in one million gallons of sewage. We know that this amount of hydroxide added to the raw sludge at Palo Alto actually serves to decrease the bulk, due no doubt to the partial coagulation and weighting of the raw sludge particles.

The Great Western Electro-Chemical Company is not interested in designing or building sewage purification plants. The work that we are doing is entirely for the purpose of finding more effective and economical methods or materials for sewage treatment as outlets for our products. When the work is finished, we shall be glad to furnish interested parties with the results of our operation and offer them our coöperation.

We wish to thank the City of Palo Alto through Mr. J. F. Byxbee, Jr., City Engineer; Prof. Chas. Gilman Hyde of the University of California; Professors Leon B. Reynolds and Paul J. Beard of Stanford; Mr. E. A. Reinke of the State Board of Health; Mr. A. M. Rawn of the Los Angeles County Sanitation Districts, and the host of other sanitary men who have given us their valuable assistance and suggestions.

Discussion

BY PAUL J. BEARD

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The possibilities offered by the data so far gathered are impressive. There are some inconsistencies it is true, but these appear to be occasioned by the mechanical difficulties that inevitably develop when any new technique is transferred to the field from the laboratory in which it was born, rather than by any inherent defect in the theory or plan.

If this process fulfills the promise offered by the data so far gathered, it should be of particular interest to California as a possible answer to some of its special problems. First from the view of shellfish contamination, of which there is at present far too much, and closely allied to this proposition, the angle of beach pollution. The effluent discharged is one that for practical hygienic considerations is sterile and apparently quite stable.

It is pertinent to consider it also in its relation to water conservation. It has always hurt my sense of the fitness of things to see a municipality go to the expense of transporting water at great expense over long distance only to throw it away. Such a treatment as has been outlined would offer, it seems, a fairly cheap yet efficient enough treatment to warrant the use of the effluent, at least for irrigation purposes.

The intermediate treatment to which Mr. Stevenson has referred opens suggestive possibilities for the small community that cannot, or need not, finance more complete treatment. The promise of low plant investment and freedom from high maintenance costs incident to more complicated procedure requiring highly skilled supervision for efficient operation is particularly appealing. The propositions I have submitted are based on the promise offered by data yet incomplete, and of course final judgment must be withheld until the promises offered are fully matured.

Discussion

BY HARVEY O. BANKS

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There seems to be a rapidly mounting interest in chemical sewage purification. The application of chemicals is subject to easy and positive control and hence may be adjusted to meet seasonal and daily variations in the character of the sewage. This is a marked advantage over biological methods, which are too easily and too frequently upset by slight overloads on the plant or by the presence of some undesirable industrial waste.

Power costs, which may be a very considerable item in certain types of treatment, are an almost negligible factor in a process such as we have

been using at Palo Alto. The only power required is that necessary to operate the mixers and the mechanism for sludge removal.

The required detention period for a chemical process may be very much less than for a biological process. This would be of major importance where land is at a premium.

Another point in favor of chemical purification is the freedom from odors about such a plant, and therefore the plant could be located in congested areas.

The most familiar and valid argument against chemical sewage purification has been the tremendous volumes of sludge produced. We believe that we have solved this problem by using the most effective coagulants and applying them so that better results are produced with a minimum of chemicals.

With our process, one of the fundamental steps is the return of the sludge from the second basin to the incoming raw sewage. This sludge consists of spent ferric hydroxide formed by the addition of the ferric chloride plus whatever is removed by this coagulation and settled out in the second basin. The addition of this sludge to the incoming raw sewage not only improves the efficiency of the first basin but makes it possible to remove the sludge from two basins at one point, which very materially decreases the total volume of sludge to be handled.

Since the sludge from this process will contain iron in the form of ferric hydroxide to the extent of 94 pounds per million gallons, the effect of this amount of iron on the treatment of the sludge becomes important. To date, we have not had time to conduct any experiments on the sludge. However, from the work of others, it seems possible that the presence of the ferric hydroxide in the sludge may have several important effects.

The sludge containing the ferric hydroxide, as drawn from the primary tank, is almost a dense black. The solids settle out of the liquid very rapidly, forming a dense, granular mass. The rapidity of settling and character of the settled material have received comment from several prominent sanitary engineers.

The possible effect of the iron on digestion of the sludge is important. Setter[1] found that ferric hydroxide caused a slight stimulation of gasification, approximately the same reduction of solids and volatile matter and approximately the same ash increase. However, he used considerably less ferric hydroxide then is the case for our sludge. In working with a sludge produced from a sedimentation basin to which ferric chloride had been added with the raw sewage, Rudolfs, Setter and Baumgartner[2] found that the rate of gasification was considerably increased during the first two-thirds of the digestion period. They also observed that the total quantity of gas produced was somewhat less. Digestion was practically completed in twenty days as against 32–35 days for an untreated sludge.

The gas peak occurred in 16 days, which was considerably shorter than for an untreated sludge. The per cent reduction in volatile matter was somewhat less. Again, the amount of iron was less than is the case for our sludge.

Upon the above considerations, we have based our conclusions that the presence of iron in the sludge, instead of being disadvantageous, may possibly be beneficial in that it may result in a decreased digestion time for the sludge and may produce a digested sludge that may dewater more easily due to the weighting action of the inert ferric hydroxide.

Successful chemical treatment depends, to a great extent, upon the proper design of mixing tanks and sedimentation basins. The mixing tanks at our plant are four feet in diameter and are operated two in series. The sewage enters and leaves these tanks tangentially to the flow. The mixing device consists of a vertical shaft in the center supporting a cross arm on which are hung two paddles. The paddles have an area of 25 per cent of the vertical cross-sectional area of the tank.

The paddles are rotated in the first tank at 10 r. p. m. and in the second tank at 3 r. p. m. This insures proper mixing in the first and maximum floc development in the second.

The inlet and outlet baffle arrangements in the sedimentation basins consist of curtain walls in which there are 6 openings each. On the basin side of each of these openings, there is a plate which serves to dissipate the jet action. The openings are in the upper two-thirds at the inlet baffle and in the upper one-third in the outlet baffle. This design has resulted in remarkable efficient sedimentation.

Bibliography

[1] L. R. Setter, "Effect of Iron on the Anaerobic Decomposition of Sewage Solids," THIS JOURNAL, **2,** 504 (October, 1930).

[2] Willem Rudolfs, L. R. Setter and Wm. H. Baumgartner, *Ibid.*, **1,** 398 (July, 1929).

The Development of a Chemical Process for Treatment of Sewage

By George H. Gleason and Alfred C. Loonam

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The entrance of the firm of Guggenheim Brothers into the field of sewage treatment came about somewhat indirectly. For several years the firm has been interested in the production and sale of nitrate of soda and they were on the lookout for new uses for this product. About a year and a half ago an article appeared in one of the technical journals concerning the use of sodium nitrate at Coney Island, N. Y., for the reduction of nuisance due to odors resulting from anaerobic conditions. After some preliminary investigation, we learned that nitrate had been used with varying degrees of success in several other communities.

In our research laboratories, work was carried on covering the use of nitrate of soda as a purifying agent, with a view to the possible development of additional markets for the product. The results of our efforts substantiated those of others, namely, that the oxygen in $NaNO_3$ is available for oxidation of certain constituents in sewage, but only in the absence of uncombined or dissolved oxygen. Confirmatory tests were conducted, using such powerful oxidizing agents as potassium dichromate, potassium permanganate and sodium ferrate. The results confirmed those obtained when using sodium nitrate.

Our next method of attack on the problem consisted in releasing the oxygen and thus making it available to do its required work. The oxygen was released from the nitrate in the form of NO_2, a powerful oxidizing agent. Sewage was treated with this gas under a wide range of conditions, and, although the results were somewhat better than from nitrate, they were not satisfactory. We hoped and expected that the NO_2 would oxidize the basic N to free N, but this did not prove true in the concentrations in which the latter were present, although this is a well-known reaction at higher concentrations.

At this point we reluctantly abandoned our idea of direct oxidation at the low existing concentrations. We were convinced that there was little hope for the use of nitrate of soda or products made from it for this purpose, because it had not proved effective and because its use would not be economical.

However, we were impressed with the importance of the general sewage purification problem and our interest in carrying it through to a solution was thoroughly aroused. Thereupon, we pursued an entirely different course. Our laboratory force had had broad experience in the recovery of sulphide minerals by the flotation operation, a process which involves many

problems of colloidal chemistry and colloidal behavior. Consequently, we decided to concentrate the putrescible materials to a consistency within the range of reaction possibilities.

We set out to coagulate the suspended solids and remove the soluble putrescible material in one step, but without much success. Among other things, we tried gelatinous silica obtained from precipitation of sodium silicate with hydrochloric acid and by calcium chloride. In subsequent experiments, the trivalent metal hydroxides precipitated from their sulphates and chlorides by various alkalis also failed to remove completely the putrescible material present. However, some of these hydroxides gave excellent clarification, although they effected no removal whatever of the dissolved materials.

As a result of these experiments, we were convinced that removal of the suspended solids and the soluble putrescible matter must be effected as separate operations. Having had a certain degree of success with coagulation, we were obliged to develop a scheme for the removal of the dissolved putrescible materials. Since these were largely basic N compounds, we used them as a criterion for the effectiveness of removal. We also noted that these soluble basic nitrogen compounds were least affected by the precipitation process.

Our experience in other lines of work led us to give consideration to adsorption of the dissolved putrescible material from solution by surface active compounds. Base-exchange zeolites were given special attention because of their ability to remove quantitatively basic nitrogen compounds, and it was considered probable that the N in solution was tied up with groups containing carbon. The removal of these elements would be a long step toward the goal we were seeking.

A sample of sewage, containing 29 p. p. m. of amino nitrogen, was clarified with 2000 p. p. m. of blood charcoal and filtered. The clarified liquid contained 16 p. p. m. of amino nitrogen. Separate samples of the effluent were then treated with surface active compounds by agitation, with the following results:

Treatment	Amino N. P. p. m.
200 p. p. m. of SiO_2 as (Na_2SiO_3 + HCl)	16
200 p. p. m. of SiO_2 as (Na_2SiO_3 + $CaCl_2$)	16
100 p. p. m. of Al as ($Al_2(SO_4)_3$ + NaOH)	14
100 p. p. m. of Al as ($Al_2(SO_4)_3$ + CaO)	14
1000 p. p. m. of Blood Charcoal	16
1000 p. p. m. of Blood Charcoal + 40 p. p. m. NaOH	14
100 p. p. m. of Zeolite	14
200 p. p. m. of Zeolite	16

In an experiment run at the same time, a sample of clarified sewage obtained from the foregoing experiment was passed through a bed of zeolite.

The effluent contained 7 p. p. m. of nitrogen, a reduction of 9 p. p. m., or 56 per cent.

In another series of experiments, a sewage having a total nitrogen con-

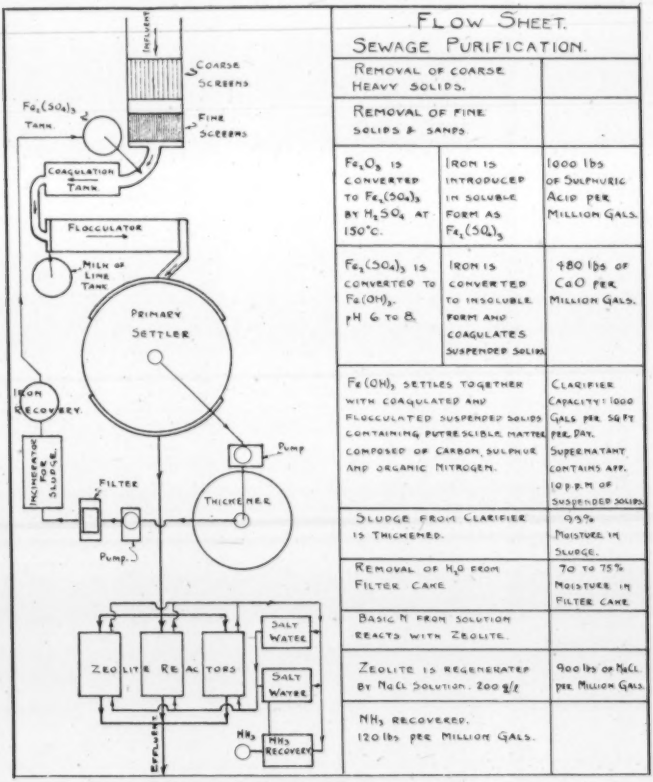
INFLUENT
COARSE SCREENS
$Fe_2(SO_4)_3$ TANK
FINE SCREENS
COAGULATION TANK
FLOCCULATOR
MILK OF LIME TANK
PRIMARY SETTLER
IRON RECOVERY
INCINERATOR FOR SLUDGE
FILTER
PUMP
THICKENER
PUMP
SALT WATER
ZEOLITE REACTORS
SALT WATER
EFFLUENT
NH_3
NH_3 RECOVERY
FLOW SHEET.
SEWAGE PURIFICATION.
REMOVAL OF COARSE HEAVY SOLIDS.
REMOVAL OF FINE SOLIDS & SAND.
Fe_2O_3 IS CONVERTED TO $Fe_2(SO_4)_3$ BY H_2SO_4 AT 150°C.
IRON IS INTRODUCED IN SOLUBLE FORM AS $Fe_2(SO_4)_3$
1000 lbs OF SULPHURIC ACID PER MILLION GALS.
$Fe_2(SO_4)_3$ IS CONVERTED TO $Fe(OH)_3$. pH 6 TO 8.
IRON IS CONVERTED TO INSOLUBLE FORM AND COAGULATES SUSPENDED SOLIDS.
480 lbs OF CaO PER MILLION GALS.
$Fe(OH)_3$ SETTLES TOGETHER WITH COAGULATED AND FLOCCULATED SUSPENDED SOLIDS CONTAINING PUTRESCIBLE MATTER COMPOSED OF CARBON, SULPHUR AND ORGANIC NITROGEN.
CLARIFIER CAPACITY: 1000 GALS PER SQ FT PER DAY. SUPERNATANT CONTAINS APP. 10 p.p.m. OF SUSPENDED SOLIDS.
SLUDGE FROM CLARIFIER IS THICKENED.
93% MOISTURE IN SLUDGE.
REMOVAL OF H_2O FROM FILTER CAKE
70 TO 75% MOISTURE IN FILTER CAKE.
BASIC N FROM SOLUTION REACTS WITH ZEOLITE.
ZEOLITE IS REGENERATED BY NaCl SOLUTION. 200 g/l
900 lbs OF NaCl PER MILLION GALS.
NH_3 RECOVERED. 120 lbs PER MILLION GALS.

FIG. 1.—Flow Sheet, Liquid and Solids.

tent of 25 p. p. m., of which 14 p. p. m. were ammonia (NH_3), was treated with 2000 p. p. m. of blood charcoal and filtered. The filtrate contained 17 p. p. m. of total nitrogen, including 13 p. p. m. of ammonia. This filtrate was percolated through a zeolite bed 1 in. in diameter and 4 in. deep, at the

rate of 600 cc. per hour, giving an effluent containing 5 p. p. m. of total nitrogen, of which 0.4 p. p. m. were ammonia nitrogen.

Tests were then conducted with the various coagulants used in previous experiments and it was learned that ferric sulphate $Fe_2(SO_4)_3$ was the

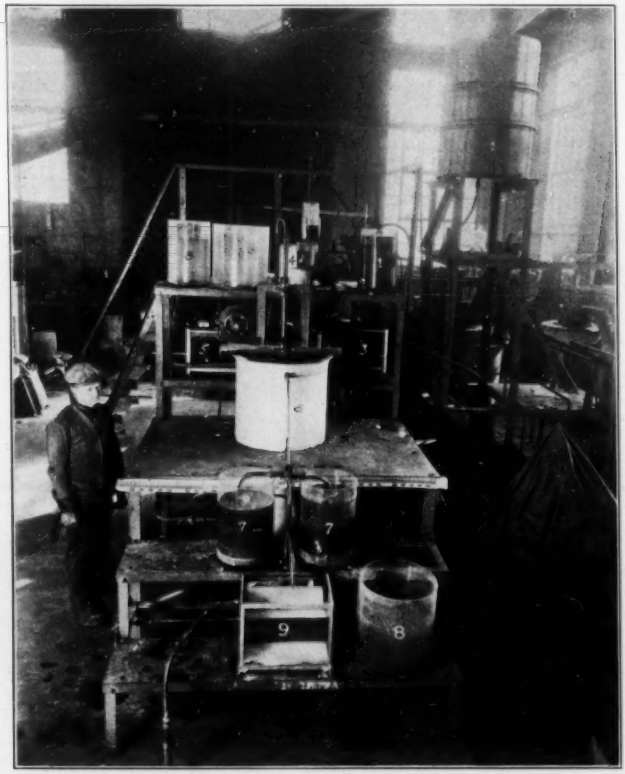

FIG. 2.—Demonstration Plant, Chemical Sewage Purification Process. Capacity 2500 gallons per day. 1, Crude Sewage Flow. 2, Ferric Sulphate Feed. 3, Ferric Sulphate Mixing and Coagulation. 4, Lime Feed. 5, Lime Mixing and Flocculation. 6, Clarifier. 7, Zeolite Reactors. 8, Brine Wash for Regeneration of Zeolite Reactors. 9, Final Effluent.

most effective of any of the series used, when judged by clarification, B. O. D. reduction, settling rate and cost. Lime was determined to be the best precipitant in conjunction with ferric sulphate.

Settling rates obtained in liter cylinders were as follows:

200 p. p. m. of Fe as $Fe_2(SO_4)_3$ 428 p. p. m. NaOH 37 min. from 700 cc. to 100 cc.
100 p. p. m. of Fe as $Fe_2(SO_4)_3$ 214 p. p. m. NaOH 50 min. from 700 cc. to 100 cc.
50 p. p. m. of Fe as $Fe_2(SO_4)_3$ 107 p. p. m. NaOH 72 min. from 700 cc. to 100 cc.

Relative settling tests, when using caustic soda (NaOH), lime (CaO), sodium carbonate (Na_2CO_3), ammonia (NH_4OH), magnesia (MgO), trisodium phosphate (Na_3PO_4) and others as precipitants, were conducted with the following results:

	200 P. p. m. Fe as $Fe_2(SO_4)_3$ Relative Settling	
	Time	Rate
NaOH	1.85	1
$Ca(OH)_2$	1.4	1.32
Na_2CO_3	1.5	1.24
NH_4OH	1	1.85
$Mg(OH)_2$	1.75	1.06
Na_3PO_4	1	1.85

Settling rates were also determined using aluminum sulphate $Al_2(SO_4)_3$, ferric sulphate $Fe_2(SO_4)_3$, chromic sulphate $Cr_2(SO_4)_3$, together with lime, for coagulation. Agitation by air was carried on for ten minutes.

			Settling Rate
$Al_2(SO_4)_3$	100 p. p. m. Al	311 p. p. m. CaO	$3^1/_2$-ft. per hour
$Fe_2(SO_4)_3$	100 p. p. m. Fe	150 p. p. m. CaO	6 ft. per hour
$Cr_2(SO_4)_3$	100 p. p. m. Cr	139 p. p. m. CaO	9 ft. per hour
$Fe(SO_4)$	100 p. p. m. Fe	100 p. p. m. CaO	6 ft. per hour

The effect of pH on settling rate was studied with the following results:

			Relative Settling	
	Lime	pH	Time	Rate
$Fe_2(SO_4)_3$ 100 p. p. m. Fe	30	3.0	5.62	1.0
$Fe_2(SO_4)_3$ 100 p. p. m. Fe	60	3.6	4.33	1.3
$Fe_2(SO_4)_3$ 100 p. p. m. Fe	90	4.4	3.75	1.5
$Fe_2(SO_4)_3$ 100 p. p. m. Fe	120	5.8	2.50	2.25
$Fe_2(SO_4)_3$ 100 p. p. m. Fe	150	6.5	1.25	4.50
$Fe_2(SO_4)_3$ 100 p. p. m. Fe	180	7.4	1.12	5.00
$Fe_2(SO_4)_3$ 100 p. p. m. Fe	210	8.0	1	5.62

This series of tests was supplemented by others in which lime was added first and iron afterward; the settling rate in this case was reduced by 60 per cent.

At this time we thought that we had sufficient preliminary information from small scale experiments to establish the essential steps of the process, and we built our first complete small unit for treatment with coagulants and zeolite.

Sewage was treated with 200 p. p. m. of iron as ferric sulphate and subsequently with caustic soda, after which the clarified supernatant liquor was passed through a bed of zeolite, with the following results:

	Raw Sewage	Clarified	Effluent
Suspended Solids	200	40	2
B. O. D. 10-day	199	60	52
Total Nitrogen	24	20	6
Ammonia Nitrogen	15	12	0.3

Then iron was reduced to 100 p. p. m. and 50 p. p. m. in succeeding tests and substantially the same results were obtained. Subsequently aluminum sulphate was used with no improvement over ferric sulphate.

As a result of this preliminary study, we were satisfied that our theory of concentration was correct and we proceeded to study the disposal of the concentrated putrescible material, *i. e.*, the suspended solids in the form of sludge and the dissolved salts in the zeolite.

The sludge has a definite heat value and it contains iron which can be regenerated as ferric sulphate for further use as coagulant. We concluded that the proper method of oxidizing this was by burning.

The dissolved basic nitrogenous material, principally ammonia, is highly concentrated in the spent regenerating salt solution from the zeolite reactors and is in a form easily available for economic recovery.

After an extended period of operation of this small unit, the results were sufficiently encouraging to warrant the construction of a model sewage plant with a daily capacity of approximately 500 gallons of raw sewage. This plant was built of glass, a construction which permitted full observation of each phase of the operation.

Many points of doubt were dispelled in the working of this plant and, as a result of the experience gained, we built in the laboratory a plant with a daily capacity of about 2500 gallons of raw sewage, this unit being complete both as to purification of the sewage and disposal of the putrescible matter.

It is significant that the results obtained from this unit were decidedly better than those from the small batch experiments. Effluents with B. O. D.'s of 20 p. p. m. were continually produced.

The process carried out in this plant consists principally of four steps (Figure 1):

(I) Removal of suspended solids by coagulation with iron compounds and lime, and settling the coagulated solids in the form of a sludge.

(II) Disposal of the sludge by filtration and complete incineration.

(*A*) Regeneration of the iron as ferric sulphate from the incinerated ash.

(III) Removal of the basic nitrogen compounds, together with attendant groups containing carbon, hydrogen, sulphur, etc., by an exchange reaction using a preferred type of zeolite.

(IV) Regeneration of the zeolite and consequent concentration of the basic nitrogen compounds in the salt solution, and subsequent recovery of ammonia from this solution.

In ordinary raw sewages and similar waste liquors, putrescible matter, consisting of carbon, hydrogen, sulphur, etc., in various combinations, is present in two forms, namely:

(1) Insoluble (suspended matter)
(2) Soluble.

The insoluble matter, consisting principally of colloids, contains simple and complex compounds resulting from the breaking down of proteins. These materials have molecular weights varying from 6000 for the simple ones to 25,000 for the more complex, and they are negatively charged.

In accordance with the Hardy Schultz law of coagulation, trivalent metallic ions, which carry positive charges, should have the greatest coagulating effect upon these colloids and, due to the molecular weight of the metals as compared with the colloids, the quantity of coagulant required is very small. It is known that these colloids exercise osmotic pressure against the medium which carries them and that the reduction of the osmotic pressure is a measure of the efficacy of coagulation of these particles.

As stated earlier, we have found that ferric sulphate has a definitely high coagulating value and we are convinced that the sulphate radical unquestionably aids in breaking down the complex colloids to simpler ones, including amino acids.

Character of Influent Sewage.—New York City sewage from the Dyckman Street outfall has been used in the operation of our experimental plants for a period of about eight months. The sewage treated has been taken from the Dyckman Street outfall covering the entire day, and the plants have been operated over sufficient length of time to cover seasonal variations. This sewage has a yearly average temperature of 57° F. However, temperatures varied from 52° to 84° F. over the duration of the run. This sewage is of the following character:

Suspended Solids..... (The suspended solids varied from 125 p. p. m. to 513 p. p. m., but the latter was unusually high)	Aver. 200 p. p. m.
B. O. D. (5 days).....	Aver. 150 p. p. m., with variation from 100–325 p. p. m.
Total Nitrogen..... (Total Nitrogen varied from 12 to 52 p. p. m.)	Aver. 24–28 p. p. m.
Ammonia Nitrogen..... (Ammonia Nitrogen varied from 6 to 20 p. p. m.)	Aver. 12–14 p. p. m.
Bacteria.....	3,000,000–6,000,000 colonies/cc.

Procedure in Operation and Results Obtained. Step I.—*Removal of suspended solids by coagulation with iron compounds and lime, and settling the coagulated solids in the form of a sludge* (Figure 2).

The incoming sewage is treated first with soluble iron, in the form of ferric sulphate solution of 50 grams per liter concentration. Prompt diffusion of the solution throughout the sewage is obtained by air agitation. The oxygen in the air keeps the iron in the ferric condition.

The ferric sulphate is added before the lime. In the majority of cases all of the iron is precipitated in this operation. A blanket of ferric hydroxide,

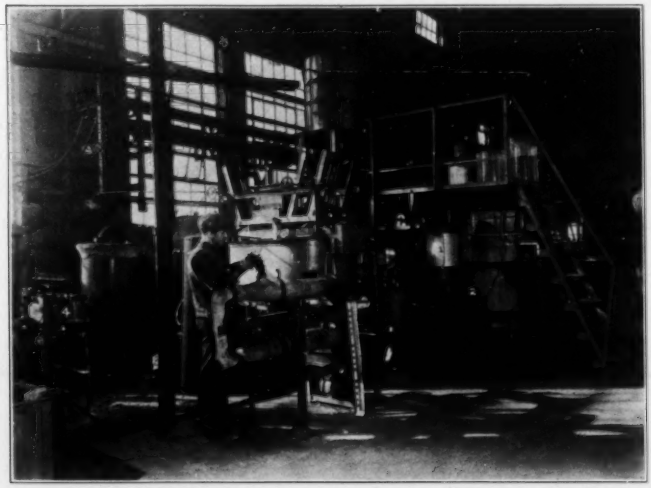

FIG. 3.—Sludge Disposal Section. 1, Sludge Thickener. 2, Vacuum Filter. 3, Filter Cake Dryer and Incinerator. 4, Acid Leaching of Incinerator Ash for Recovery of Ferric Sulphate.

in a medium having a pH of 5 to 6.5, is formed and acts as a collector of the suspended material. In the earlier operations 50 p. p. m. of iron in the form of ferric sulphate were used. This was reduced gradually to 30 p. p. m., an amount found ample to produce satisfactory coagulation and precipitation of the suspended solids.

Time of retention	5 minutes
Iron concentration	30 p. p. m. of iron or 105 p. p. m. of ferric sulphate
Air requirements	.07 cu. ft./gal.

In the next stage of the operation, the lime is added as milk of lime in 50 grams per liter concentration to give a pH consistent with maximum settling rate and optimum operation of the zeolite filters. Lime is preferable to other alkalis for this operation because it gives a denser floc and one which settles very rapidly, and, furthermore, it is relatively inexpensive.

This addition of lime takes place at the entrance of a tank equipped with a flocculating mechanism, which serves to disperse the lime and condition the floc. The time of flocculation was studied in relation to settling rate and filtration rate, and it was found that the range of time for producing best conditions is limited. If flocculated for a long period there is a tendency to revert back to the dispersed condition.

From the flocculator the material passes to a clarifier, into which the sewage is introduced at the circumference near the bottom, passing upward through a blanket of sludge. The clarified liquid overflows and the sludge is removed from the bottom by the usual clarifier operation. The supernatant liquid is substantially free from suspended matter and is ready for treatment to remove the soluble material.

The pH values throughout the system are controlled and maintained, preferably from 6 to 8, although the system is operated very satisfactorily over a wider range, namely, from 5 to 9.

Settling area of clarifier	800 gals./sq. ft./day
Suspended solids in sewage entering clarifier	269 p. p. m. average
Suspended solids in supernatant liquid	10 p. p. m. average

Up to this point, approximately 60 per cent of the putrescible material has been removed and the total nitrogen reduced from 28 p. p. m. to 15 p. p. m., about 12 parts of which are present as ammonia nitrogen.

Step II.—*Disposal of the sludge by filtration and complete incineration.* (*A*) *Regeneration of the iron as ferric sulphate from the incinerated ash* (Figure 3).

The sludge from the bottom of the clarifier is pumped to a suction filter, where the moisture is reduced by about 80 per cent.

Moisture in sludge entering filter	93%
Moisture in filtered sludge	70–75%
Filtration rate (filter cake)	7 lbs./sq. ft. of filter surface/hr.

The organic matter in the cake from the filter is completely destroyed in a rotary kiln incinerator consisting of two sections, namely, a drying section and a burning section. In both the drier and incinerator sections of the unit the air travels concurrently with the solids and gases.

Moisture in incoming filtered sludge	70–75%
Temperature, entering end of dryer	150° C.
Temperature, exit end of dryer	110° C.

The dried sludge is fed into the incinerator section, where all putrescible material is completely destroyed by burning.

Incinerating temperature	650–700° C.
Calorific value of sludge	4500–5000 B. t. u./lb. by bomb calorimeter test

The temperature is kept below 700° C., so that no sintering of the ash is encountered. A substantial amount of the heat is obtained from the burning of the sludge. This temperature was found sufficiently high to destroy the putrescible matter. The calorific value of the sludge is such that in a large-scale operation no fuel will be required for incineration.

The incinerator worked for several months substantially without odor. In fact, when operated within its designed capacity, there was no evidence of nuisance and no smoke. However, when the unit was overloaded or when attempts were made to reduce the incinerating temperature below 600° C., or decrease the amount of air, objectionable odors developed rather promptly.

The ash obtained has the following analysis:

Incinerated residue:	Fe_2O_3	41.2%
	Al_2O_3	8.68
	CaO	7.32
	MgO	1.31
	$CaSO_4$	4.20
	$CaCO_3$	1.87
	Na_2O	.30
	SiO_2	24.00
	Other Constituents	9.34
	Loss on Ignition	1.78

This ash is treated with sulphuric acid for the regeneration of the ferric sulphate, which is again used for coagulation. This regenerated ferric sulphate gave better coagulation results than did C. P. ferric sulphate or any other commercial ferric sulphate obtained.

The small amount of insoluble matter, consisting principally of silica, remaining after the treatment of ferric oxide with sulphuric acid, is filtered off and discarded.

Step III.—*Removal of the basic nitrogen compounds, together with attendant groups containing carbon, hydrogen, sulphur, etc., by an exchange reaction using a preferred type of zeolite.*

The supernatant liquid from the clarifier passes through a specially prepared zeolite reactor bed. In this operation, the basic nitrogen, principally ammonia, is exchanged for the sodium in the zeolite. As a result of this operation, there is a high concentration of ammonia in a very small volume of reactor.

Amount of zeolite required.....	16,000 lbs./million gals. sewage treated
Rate of loss of zeolite.....	5 to 7% per year.

Step IV.—*Regeneration of the zeolite and concentration of the basic nitrogen compounds in a salt solution, and subsequent recovery of ammonia from this solution.*

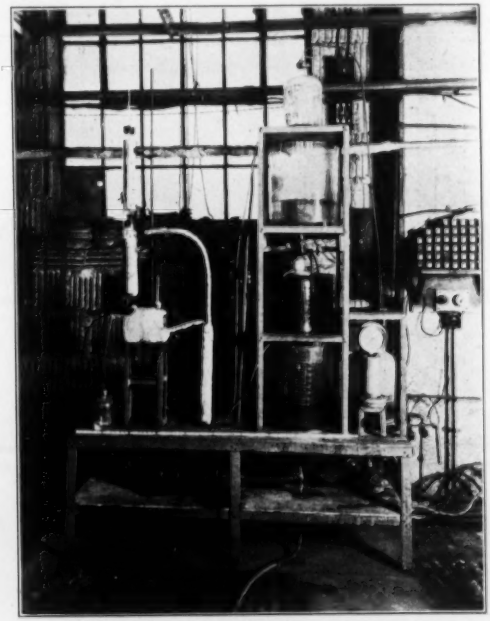

FIG. 4.—Ammonia Recovery Plant.

After ten or twelve hours, the flow is diverted from one zeolite reactor to another, the first one being regenerated by a backwash of salt water, containing approximately 20 per cent sodium chloride. By this operation, the basic nitrogen transfers from the zeolite to the salt solution.

We have definitely observed that the zeolite bed does not become septic, because the backwashing by a concentrated salt solution prevents the growth of bacteria. In the earlier stages of our development, we used a

rapid sand filter for the clarifier overflow to protect the zeolite beds, but this was discarded because it did not prove necessary to our purpose and, also, it became septic. The zeolite beds perform the double function of removing the small remaining amount of suspended matter by filtration and of removing the basic nitrogenous groups by means of reaction. That this nitrogenous material is highly putrescible is demonstrated by the fact that the salt solution after regeneration had a B. O. D. of 1350 p. p. m.

The basic nitrogen compounds are recovered from the brine solution in accordance with usual practice in a suitable type of standard equipment. In our operations the amines have been recovered as an aqueous solution of about 30 grams per liter concentration, calculated as ammonia.

The operation consists of treatment of the spent backwash with lime to release the amines and recovery of same by distillation and condensation (Figure 4). On a large scale, the liquor thus obtained is concentrated to anhydrous amino compounds, principally ammonia, by means of multiple effect evaporators. The salt solution, stripped of these compounds, again becomes available for further regeneration of the zeolite bed.

Amino nitrogen content of supernatant liquid	14 p. p. m.
Concentration of same in backwash	2.0 grams per liter
Ratio concentration in backwash to that in sewage	200 to 1
Amount of backwash required	1.0% of sewage flow
Recovery of ammonia (NH_3)	100 lbs./million gals.

Sampling.—Samples were taken every hour and made into eight-hour composites. Sampling was carried on in accordance with directions of the A. P. H. A. and the Joint B. O. D. Committee of the Great Lakes & Ohio River Boards of Public Health Engineers, as described in THIS JOURNAL. Check analyses were obtained periodically from an outside firm of analysts.

COMPARISON OF RAW SEWAGE WITH PURIFIED EFFLUENT

	Raw Sewage	Purified Effluent
Suspended Solids	Aver. 200 p. p. m.	1 p. p. m.
B. O. D.	Aver. 150 p. p. m., with variation from 100–325 p. p. m.	5 p. p. m.
Organic Carbon	Aver. 200 p. p. m.	20 p. p. m.
Total Nitrogen	Aver. 24–28 p. p. m.	2–3 p. p. m.
Ammonia Nitrogen	Aver. 12–14 p. p. m.	0.5–1.0 p. p. m.
Bacteria	3,000,000—6,000,000 colonies/cc.	
Total Bacteria Removal		99.1%
B. Coli Removal		99.6%

Equipment and Materials.—The equipment used throughout the process was patterned after standard equipment which has been employed for similar purposes, either in sewage disposal plants or in other industrial operations. Ratios between rates of flow, tank area and filter size have been maintained to simulate those employed in actual practice. The

materials used, namely, sulphuric acid, burned lime and common salt, are among the cheapest of heavy chemicals and are readily available.

Plant Construction and Expenditure.—Preliminary designs indicate that the space required for this type of plant is about 50 per cent of that required for other types of plants producing approximately equal purification.

Our study leads us to believe that one of these plants, with a capacity of 50,000,000 gallons or more per day, can be installed at a cost of approximately two-thirds of the cost of an activated sludge plant of corresponding capacity.

Cost of Operation.—Our estimates indicate that the cost of operating and maintaining a chemical process plant with a daily capacity of 50,000,000 gallons or more would be about $22.00/m.g.d. (In this figure, no credit is taken for the ammonia recovered and no account is taken of interest or amortization charges.)

All of the above figures are based on prices for material and labor existing in the eastern section of the United States or in the Great Lakes cities at the present time, and might vary up or down for other localities in the United States or the rest of the world.

This ratio of cost can be maintained if there is a reduction of construction cost due to lower material and labor prices.

Conclusion.—The data given in this paper have been obtained in the actual operation of a model sewage plant, complete in every detail, covering 24 hours per day for about eight months. As a result of this work we feel that we have a process possessing several distinct advantages over other types giving equal purification. These advantages are:

(1) Simplicity of operation.
(2) Lack of sensitiveness to changing conditions in sewage flow.
(3) Relative saving of space.
(4) Lower cost of installation.
(5) Lower cost of operation.

We are now constructing a demonstration unit of a capacity of 25,000 gallons of raw sewage per day, which we expect to install at the North Side Sewage Treatment Works, Chicago, for operation in conjunction with the Sanitary District of Chicago.

Observations on Bulking in a Surface Aeration Activated Sludge Plant*

BY G. M. RIDENOUR

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During a study of the effect of increasing quantities of suspended solids (by volume and weight) in an institutional sewage treatment plant, observations were made on the activated sludge "bulking" which occurred during that time.

The data were collected over a continuous period which began with the starting of the plant, extended through a period of very effective purification and ended up with severe bulking. Hence, it is thought it will be of interest to trace some physical and chemical changes in the aeration tanks during those periods in relation to the purifying and settling characteristics of the activated sludge floc.

The general design features of the plant, character of raw sewage and general operating results were given in a recent publication.[1] Briefly, the sewage treatment process consists of primary settling tanks, separate sludge digestion, aeration tanks provided with surface brush aeration, final settling tanks and chlorination.

The average composition of the raw sewage reaching the plant is approximately equivalent by analysis to the usual domestic sewage containing no industrial wastes. The average analyses of the composited sample of raw sewage is:

pH	7.8	Dissolved Oxygen	1.0 p. p. m.
Suspended Solids	156 p. p. m.	B. O. D. (5 day)	235 p. p. m.
Settleable Solids	3.5 cc. per liter	Total Acidity	0.5 p. p. m.
Total Solids	580 p. p. m.	Total Alkalinity	130 p. p. m.
Ether Soluble	43.3 p. p. m.	Chlorides	21 p. p. m.

The composition of the sewage after passing through the primary settling tank and before entering the aeration tank is:

pH	6.9	B. O. D. (5 day)	185 p. p. m.
Suspended Solids	94 p. p. m.	Total Acidity	13 p. p. m.
Settleable Solids	0.3 p. p. m.	Alkalinity	100 p. p. m.
Total Solids	456 p. p. m.	Chlorides	21 p. p. m.
Dissolved Oxygen	0.0 p. p. m.		

The general operating conditions prior to and leading up to the short bulking period which occurred at this plant are briefly summarized as follows:

On July 20, 1931, after a short period of initial operation the plant was

* *Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Sewage Research.*

re-started. Uninterrupted operation was continued from that date on until September 18, when a serious case of "bulking" occurred.

During this entire period the suspended solids in the aeration tank were allowed to accumulate slowly. The brushes were run between 64 and 72 r. p. m., which was a sufficient speed to provide an ample supply of air to the tanks at all times.

The detention time in the aerators from July 20 to Sept. 1 was maintained at 4.4 hours on the basis of average daily sewage flow, and 3.6 hours on the basis of average maximum flow, which prevailed about 14 hours during the day. On Sept. 1 the aeration period was increased to 8.8 hours on average flow basis. This same detention period was carried throughout the bulking period.

The detention period in the final settling tank during the entire period July 20 to Sept. 18 was 2.8 hours on the average daily flow basis and 2.4 hours on a 14-hour flow rate.

The data which were recorded on the aeration tanks were confined to the routine plant tests, namely, total suspended solids by weight, volatile solids by weight, volume of solids in $^1/_2$ hour settling time, dissolved oxygen, biochemical oxygen demand and suspended solids on the supernatant liquor of the activated sludge mixture in the aeration tanks after half-hour settling time. Some microscopic observations were also made on the structure of the activated sludge floc and the types of protozoa present during the bulking period.

Data Prior to and Including Bulking Period

The results of the different determinations are plotted in Figure 1 for the period from July 20, when the plant was re-started, until September 18, when severe bulking occurred. Three separate periods can be traced in this figure.

From July 20 to August 13 purification of the sewage gradually improved under the increasing accumulation of suspended solids in the aeration tanks. The (5-day) B. O. D. of the settled liquor at the outlet end of the aeration tanks dropped from 27 p. p. m. with total suspended solids content of 580 p. p. m. to 3.0 p. p. m. on August 13 after suspended solids in the aeration tanks had increased to 680 p. p. m. Suspended volatile matter during the same period increased from 350 to 440 p. p. m. Of special significance during this period of accumulation of suspended solids is the correspondingly greater rate of increase in volume of solids per liter after $^1/_2$ hour's settling. Total suspended solids on August 13 had increased to 1.17 times the original amount on July 20, and volatile suspended solids increased to 1.26 times the original amount. However, the volume of these solids increased to 5.6 times the original amount. This increasing trend of volume per unit weight can be further

observed in the curves for ratio of weight of suspended solids in p. p. m. to volume in cc. per liter after $^1/_2$ hour's settling. This ratio decreased from 9.6 to 2.0 for total suspended and from 6.0 to 1.3 for volatile suspended solids.

The second period shown on the curves lies between Aug. 13 and Sept. 1, when the purification efficiency of the aerator was at its maximum, producing a settled liquor at the outlet end of the aerators with a (5-day)

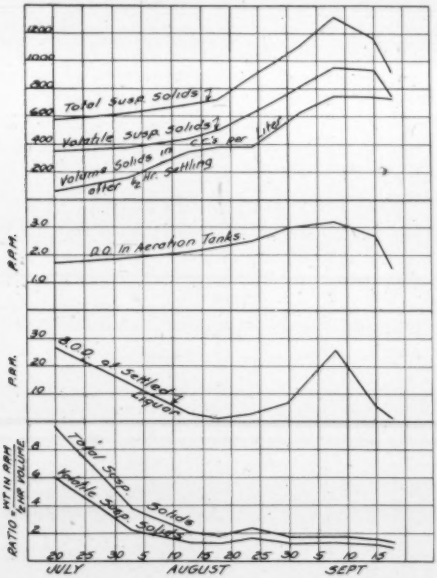

FIG. 1.—Some Chemical and Physical Relations in Aeration Tanks of Hillsdale Activated Sludge Plant.

B. O. D. less than 5.0 p. p. m. The suspended solids in the aeration tanks at the end of this period had reached 1050 p. p. m. Volatile suspended solids reached 760 p. p. m. Volume of solids after $^1/_2$ hour settling increased to 560 cc. per liter. As in the first period, the volume of solids increased at a greater rate than the solids by weight. The difference in rate of increase was, however, considerably less than in the first period. The ratio of weight to volume was 2.0 at the beginning and 1.8 at the end of the second period.

The third period is taken as beginning with Sept. 1 and continued through the serious bulking on Sept. 18. On Sept. 21, in spite of an increased amount of suspended solids and an increase of dissolved oxygen in the aerators, the purification process was marked by a rapid decrease in the purification efficiency. As far as known all conditions of operation at that time were the same as before with the exception of the increased solids content. On September 8 definite indications of bulking occurred

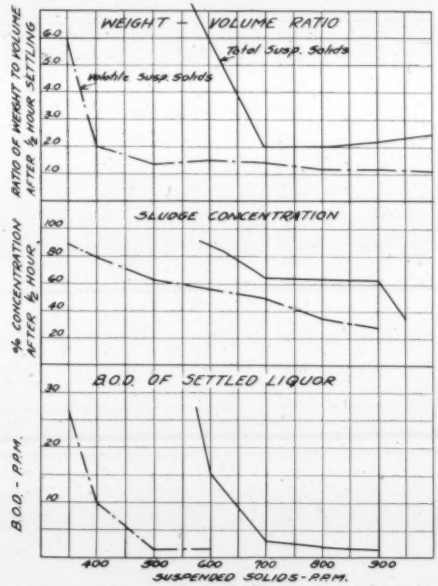

FIG. 2.—Relation of Sewage Purification to Amount of Solids in Aeration Tanks.

and rapid withdrawal of solids from the aerators was started. The bulking tendency continued and in fact increased to such an extent that on September 18 two-thirds of the original volume of solids in the tanks were automatically lost over the final settling tank weir. The increase in bulkiness of sludge after what might be termed the critical point on Sept. 8, where definite physical bulking indications arose, was quite rapid in spite of heavy withdrawal of solids. Although the suspended solids in the aerators were rapidly reduced by weight, the volume of solids after

1/2 hour settling remained practically constant. This condition is reflected in the solids volume ratio which reached 1.4 for total suspended and 1.0 for volatile suspended on September 18 when the most serious bulking occurred. The only available determination during this third period to show any decided change in trend prior to the approach of bulking was the B. O. D. determination on the supernatant liquor at the outlet end of the aerators. This 5-day B. O. D. increased very rapidly after Septem-

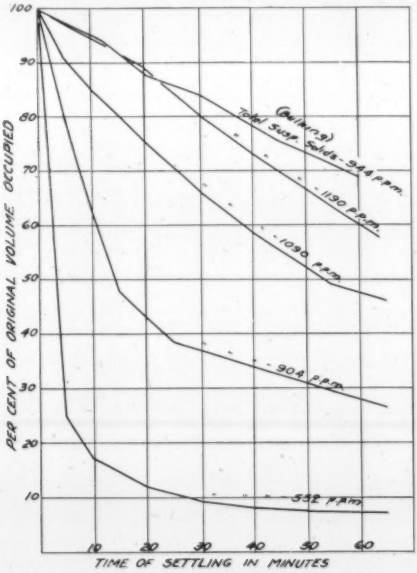

FIG. 3.—Characteristic Settling Curves for Different Amounts of Solids in Aerators.

ber 1 and was accompanied by a corresponding increase in finely divided suspended solids. If the B. O. D. serves as a criterion in this instance, the beginning of conditions favorable to bulking occurred about August 20 when the upturn in B. O. D. began.

Of primary interest to this study was the amount of suspended solids required in the aeration tanks to secure most efficient purification of the sewage. This factor must also necessarily be tied up with settling characteristics of the activated sludge floc formed. Figure 2 shows that the

purification effect of the activated sludge floc had reached its maximum value when total suspended solids reached 700 p. p. m. or total suspended organic solids reached 500 p. p. m. Corresponding to this minimum value of solids the sludge concentrated to 40 per cent of its original volume in $^1/_2$ hour's settling and the ratio of weight to volume was 2.0 for total suspended solids and 1.4 for organic suspended. The curves in Figures 2 and 3 also show that after this maximum peak of purification was reached, additional suspended solids were more detrimental than valuable, because of the attendant decrease in rate of solids concentration, which eventually resulted in bulking.

The trend of the curves previously shown have been duplicated time after time and all attempts to establish any other equilibrium coincident with good purification of sewage have been unsuccessful.

Discussion

Past experiences at this surface aerated activated sludge plant with a sewage which appears to be closely similar to a normal domestic sewage show considerably different operation requirements from those reported from other activated sludge plants where air is blown into the sewage. The major differences lie in the amount of permissible suspended solids in the aeration tanks for best results, the settling characteristics of the activated sludge floc formed, the required detention period in the aerator and the detention period required for the final settling tank.

The weight of suspended solids ordinarily carried in aeration tanks ranges between 2000 to 4000 p. p. m. Under the physical conditions of operation at this plant as previously outlined with respect to detention periods, etc., an attempt to reach a figure of even 1300 p. p. m. suspended solids resulted in severe bulking. Best results were obtained with between 700 and 900 p. p. m. total suspended solids and 500 to 600 organic suspended solids. Within this range of solids, quite effective purification of sewage occurred, with a negligible suspended solids content in the final effluent (less than 5 p. p. m.).

The rate of concentration of the activated sludge floc formed at this plant is much slower than ordinarily found at plants which carry higher concentrations of solids. This rate of concentration was found to decrease in inverse proportion to the increase in suspended solids in aerators from the very beginning of operation and ultimately resulted in bulking.

As a result of the lesser rate of concentration of the floc formed at this plant, it has been found that a longer detention period in the final settling tanks is required than ordinarily provided. Under the most favorable concentrations of solids in the aerators, namely, 500 to 550 p. p. m. volatile suspended solids or 700 p. p. m. total suspended, and a sludge which concentrated to 40 per cent of its original volume in $^1/_2$ hour settling,

a minimum of 2 hours detention in the final settling tank was required to prevent excessive solids in the effluent. The practical detention period has been found to be 2.5 hours.

The main question which naturally arises in connection with these characteristics is, what factor or factors might cause the low limit of the maximum suspended solids that can be carried in the aeration tanks without development of bulking. All observations so far at this plant discourage any attempt to lay the cause to any specific factor. The most that can be said is that the influence of all ordinarily suspected or known primary causes have apparently been absent.

The presence of sufficient oxygen in the tanks from the beginning of operation is confirmed by the D. O. curve in Figure 1. This is further confirmed by the fact that the floc formed has been of a golden brown color at all times.

The detention period in the aerators seems to have had no influence within the ranges observed. Detention periods have varied between 3.5 to 8.8 hours with no appreciable effect on the settling properties of the floc.

No relation between temperature and the chemical and physical results have been observed.

The return sludge has been maintained in a very fresh condition at all times. Best settling results appear to be obtained when the return sludge floc is finely divided.

The possibility that the raw sewage may have been of such a character as to stimulate the development of filamentous forms of growth observed in the floc appears to be eliminated by virtue of the similarity in chemical analysis of the raw sewage with other normal domestic sewages.

Another factor whose importance has not yet been determined is the type of aeration, *i. e.*, whether surface aeration of this type stimulates certain physical or microbiological activities favorable for the development of a voluminous floc and whether this same factor is responsible for the very effective purification observed at this plant with low solids concentration in the aerators. Further investigations are being conducted with respect to these two factors. This investigation consists of a direct comparison between surface aeration and compressed air.

The experiences outlined in this paper tend to show the ineffectiveness of attempting to apply any general indices that are at present proposed for operation control of activated sludge plants. Two of the most commonly proposed indices, apparently based upon average operating experiences are (1) the amount of suspended solids in the aerator as a measure to secure effective purification and (2) the ratio of weight of solids to volume after a definite time of settling.

As previously shown the amount of suspended solids in the aerators

that is required at this plant for equally effective purification is far below the usual range of concentration.

The sludge index[2] has proved of little practical value here, since the difference in the index value during a period of best purification and settling (2.0) and the beginning of bulking (1.8) was too little to be of service. There were also times during each period when this value was approximately equal. Neither was the value of unity[3] proposed as the dividing line between good and bad sludge applicable to this case. The value of unity for total suspended solids volume ratio after $^1/_2$ hour's settling was not even reached when bulking was most severe. The organic suspended solids value did however reach unity when the severe bulking occurred.

It appears that general indices devised for plants operated with compressed air cannot be applied directly to plants where surface aeration is practiced. Similar results have been obtained at Collingswood[4] and Woonsocket.[5]

At the plant under discussion the major index used for control is the organic suspended solids in the aerators. It has been definitely established that below a certain minimum value poor purification results and above a definite maximum bulking occurs. However, this index is too intimately tied up with other characteristics of the plant design to be of any practical value elsewhere.

Other factors which are viewed with respect to predicting bulking are a rapid increase in D. O. in the aerators, a rapid increase in B. O. D. and an increase in the filamentous character of the activated sludge floc.

Summary

Operating data and bulking experiences at a surface aeration activated sludge plant treating a normal domestic sewage are given. The data were collected over three periods, (*a*) beginning of operation, (*b*) period of good plant results, and (*c*) bulking.

Experiences at this plant show considerably different operation requirements than at other activated sludge plants where compressed air is employed. Unusually low amounts of suspended solids in the aerator must be maintained or bulking results. Very effective purification occurs even with the low solids concentration.

Commonly used indices for plant operation proved to be of little value.

Indices used here to predict bulking are, volatile suspended solids, increase in D. O., rapid increase in B. O. D. and increase in filamentous character of activated sludge floc.

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Plant Operation

How to Start a New Sewage Plant*

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Satisfactory operation of a sewage treatment plant is dependent upon its location, design and construction, and particularly upon the skill with which it is operated. If the plant is to be located in a high-class residential district, advantage should be taken of the best modern practice by providing in the design those appurtenances which have proved satisfactory in minimizing complaints as to odors, flies, smoke, etc.

In the starting of a new sewage plant, it is frequently found that the initial small sewage flow, with accompanying low velocities, results in deposits of solid matter in the sewers and influent troughs of the settling tanks. If this temporary condition cannot be economically provided for in the design and construction, and must be cared for in the operation and maintenance, this additional labor charge should be recognized and provided for.

Likewise, at such times of low flow, the excessive detention period in the settling tanks may increase the rate of biochemical oxygen demand of the tank effluents and thereby add to the cost of oxidation and chlorination, if these are employed.

In the construction of the sewage works and appurtenances, all surfaces in contact with the sewage or sludge should be smooth and free from projections, so as to avoid impingement of the sludge particles. Water and air pipe lines should be amply provided with valves so as to maintain operation in times of pipe line failures and during repairs. Where stoppages are likely to occur, as in sludge lines and in the distribution system of trickling filters, it is essential that means for cleaning be provided by clean-out and blow-off valves. Sewage plants using large quantities of purchased electrical power should be provided with more than one source of supply. For the maintenance of mechanical equipment, there should be on hand at all times spare parts for the replacement of those parts most likely to wear out or fail in operation.

Progress in the design and construction of sewage works includes the employment of many automatic and labor saving devices, but the need

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for skilful and intelligent operation still remains. There is considerable evidence to emphasize the need of good operation. Some plants, admittedly of excellent design and construction, have failed because of poor operation, while others of less favorable design and construction have served well due to skilful handling upon the part of the operator.

In starting operation of a sewage plant, it is of considerable moment that a competent operator be secured. In considering the many ramifications of the modern sewage works, it is evident that its operation and maintenance require a great diversity of knowledge and training. Briefly, these may include chemistry, bacteriology, steam, combustion and electrical engineering, pneumatics and hydraulics, also pipe fitting, bricklaying, cement working, carpentry, machine repairs and operation, keeping of records of operation and the ability at times to handle a pick and shovel. In addition thereto, larger plants include the responsibility of directing labor and of purchasing material and supplies.

In spite of the scarcity of those who can meet all of these requirements satisfactory plant operators have been developed among men of limited education and training, but who have been observing and eager to learn. This has been accomplished by coöperation upon the part of the operator, the designing engineer and the health authorities having jurisdiction. Short courses in plant operation provided by several of our state colleges have also been helpful in developing satisfactory operators.

In the early days, during development of the large modern mechanical equipment, it was customary for the manufacturer to furnish trained men to operate the equipment furnished by them until such time as the customer's employees were sufficiently trained and capable of taking over this responsibility.

Our sewage treatment plants represent, also, a great capital investment, and are just as complex as the mechanical equipment before mentioned. Failure to operate these plants properly may result in sad experiences to those in responsible charge and place an unfair burden upon the taxpayer in the matter of damages.

Having secured the right man, those in responsible charge are further obligated to see to it that this man is provided with the necessary labor and facilities to operate and maintain the plant, and it is to the interest of all concerned that the designing engineer and the health inspector visit the plant and confer with the operator at frequent intervals, particularly during the early stages of operation. It is to the credit of many of our outstanding engineering firms and Departments of Health that they are giving to the sewage works operator this coöperation.

Prior to placing the sewage works in operation, the operator should be furnished with a general plan and made familiar with the plant layout and the location of valves and pipe lines. He should have a clear idea

as to the requirements to be met by the plant as a whole, and of the several operating units. Printed forms should be provided for the daily recording of the detailed operation of each unit. It is surprising how valuable these records may be if the operator is willing each day to give a few minutes time to making them complete in every detail, and to reporting any unusual occurrences not otherwise clearly provided for in the records.

Before turning sewage into the plant, the operator should make certain that all bulkheads, tools, etc., left by the construction forces have been removed from the pipe lines and conduits. He should try out all water and air pipe lines and make sure that they are amply protected from freezing; turn over all mechanical moving parts to insure their being in working condition.

It is good practice to fill sedimentation tanks with clean water prior to beginning operation. This permits a checking of the tanks for leakage, provides an opportunity to try out the sludge removal equipment as well as aerators where installed, and appears to offer better distribution of the sewage solids when sewage is first admitted to the tanks.

If grit chambers have not been provided, it occasionally happens that considerable quantities of heavy mineral matter have escaped into the tanks from the sewer construction. This may result in a heavy deposit of undigestible solid matter in the tanks which is not easily removed. In the case of several two-story tanks, it has been necessary to close down the tanks and employ special equipment for removing this mineral matter from the tanks. Frequent examination of the character of the solid matter deposited in the tanks should be made, particularly during the early stages of operation, so as to avoid a great concentration of such mineral material and the resulting difficulties of removal. It is obvious that no materials should be permitted to enter the sewer system which might form deposits therein or result in injury to the structures or to the subsequent treatment processes at the sewage works.

If a large portion of the total flow originates in institutions or certain manufacturing plants, difficulty may occur in operation due to the presence of considerable rags in the sewage. These add materially to the cost of maintenance of sewage pumps and may impede sludge digestion and withdrawal. It is frequently found that this material can be intercepted near the point of origin by the installation of screens, at small maintenance cost to the establishment responsible for the discharge of this undesirable material.

Fats, oils and greases in large quantities are likely to add difficulty to sewage plant operation. Such materials should be intercepted near the point of origin by the installation of adequate grease traps of proper design. Where screens are employed, they should be cleaned frequently and the screenings disposed of promptly. In some plants screenings are satisfactorily disposed of by burying in pits or covering with grit from the

detritus chamber. At other plants incineration is employed. In the Baltimore plant screenings are cut up into smaller particles, returned again to the sewage and settled out as sludge in the settling tanks prior to digestion in separate sludge tanks.

In the absence of high temperatures and with a short stack the writer was able to reduce odor complaints by washing the screenings with tap water prior to incineration. Where incineration is employed, the temperature in the combustion chamber should be high and the smoke stack tall, to minimize smoke and odor complaints.

Grit chambers, where employed, should be cleaned frequently and much study given to velocities therein so as to provide a maximum interception of mineral matter and a minimum deposit of organic matter. Grit as removed from the chamber is likely to have more or less unpleasant odors, but these odors should not persist for more than a few days and can easily be eliminated by washing with tap water.

Settling tanks should be designed and operated so as to remove from the sewage the greatest amount of solid material present with the minimum deterioration of the liquid as determined by the biochemical oxygen demand test. With domestic sewage, this condition is usually met within the limits of a two to three hour detention period. The course of dye water through a settling tank will frequently indicate a much shorter detention period than the theoretical period or that practicable of attainment. This is probably caused by a short circuit which may frequently be corrected by the adjustment of the baffles.

In addition to scouring velocities throughout the sewer system and frequent cleaning of grit chambers and influent troughs, it is highly important that the precipitated solid matter shall be removed from the settling tanks before septic action begins and the solid matter rises to the surface of the tanks. In two-story tanks the sloping septum walls and the slot over the digestion compartment should be kept free of deposits at all times.

As warmth is one of the essentials of satisfactory sludge digestion, the late autumn or winter months appear to be less favorable for beginning sludge tank operation. The use of newspapers, stable manure and ripe sludge for seeding new sludge tanks is reported as having some merit, but the volume of seeding material required is frequently too great to justify the transportation costs.

Excessive quantities of rain water or infiltrated ground water during the early stages of plant operation, when the normal sewage flow is small may tend to reduce temperatures in the digestion compartments of the two-story tanks and thus retard sludge digestion.

Where mechanical skimming devices have not been provided, hand nets may be used for removing floating material from the surface of the settling tank. As these skimmings do not readily respond to digestion

it has been found desirable in many places to bury this material as soon as it is removed from the tanks.

Where automatic dosing appliances are installed for applying sewage to trickling filters or contact beds, the operator should thoroughly familiarize himself with their construction and details of operation, and make sure that all are in proper working condition.

Where aeration tanks are employed, as in the activated-sludge process, it is essential that the circulating velocity of the sewage be sufficient to prevent deposition of the solids.

The use of naked flames around sewage treatment works should always be discouraged. Accidental discharges of inflammable material into the sewage system, and the highly explosive nature of the gases in sludge digestion tanks, are sufficient reason for the greatest caution at all times.

Where chlorination is employed, the operator should familiarize himself with the operating features of the apparatus and see to it that there are no leaking joints in the pipe line. He should recognize the highly corrosive action of chlorine gas on certain metals and the danger to humans in contact with the gas, and should endeavor to provide the necessary safeguards.

Where multiple units are employed, each should be assigned a number, and this designation used in all records and reports of operation.

A system of sampling stations should also be established and a number assigned to each station. These stations should be numbered consecutively ranging from the lowest number at the influent end of the plant to the highest number at the effluent end.

For the determination of settling solids, Imhoff graduated cone glasses should be provided for the field tests. Apparatus for the determination of pH values, and where chlorine is used, apparatus for determining residual chlorine, may be secured at small cost and will be found of much value in the field tests. Samples for laboratory determination should be collected regularly, and so scheduled that the work of the laboratory may proceed without undue confusion and the determinations made promptly after collection. The volume of the sample and the method of collection should be determined by agreement between the chemist and the operator. Sampling requires skill and judgment, and is deserving of much thought and ingenuity upon the part of the operator and the chemist if the determinations are to be of any value.

Much literature is available on the subject of sewage treatment, as a result of research in the laboratory and in the field, and it would be well for the operator to learn of the experiences of others. The operator should also visit as many other sewage treatment plants as time will permit, as the experiences of others may be helpful to him when he faces the task of starting and placing a new plant in operation.

Discussion

MR. CAMERON: I think proper facilities should be provided in starting plants—both labor and tools. Every plant, large or small, should be equipped with a fair sized workshop and an adequate set of tools. It is exasperating when the line breaks—which is likely to happen—not to have tools in the plant suitable for the repairs.

A MEMBER: What do you do in case a lot of oil and tar comes to the plant—what procedure do you use?

MR. BEAUMONT: We had a sad experience with fuel oil. One of our industrial plants in Philadelphia used 1,000,000 gallons of fuel oil a week and a car load of it entered the sewer system. Some one told me an Imhoff tank was on fire. Well it was! But we smothered the fire. The thing to do is to keep the oil out of the sewer system. We made a survey of the industries along the sewer system, making note of the business and the character of materials used. When these occurrences would arise we would go to the men and point out what happened and we have seen to it that they took the necessary precautions to prevent accidents which otherwise might have occured. Some plants have acid discharges and some alkali discharges. There is one oil that we do handle every week and that is crank case oil. We have to skim it off. Sometime they will learn not to dump it into the inlets. When we catch any one, we call the police force.

MR. C. C. AGAR, *New York State Department of Health:* What do you do with it after you skim if off?

MR. BEAUMONT: Bury it.

MR. LINN H. ENSLOW, *Editor, "Waterworks & Sewerage:"* There is an oil trap which automatically shuts it off from the sewer. Ever have any experience with that?

MR. BEAUMONT: Our laws state that grease traps shall be placed under city inspection. If they are properly maintained they are satisfactory.

DR. E. M. SLOCUM, *General Reduction Co.:* I might suggest that waste oil is excellent for mosquito spraying. In the South people can't get enough of it. It is also used on highways.

DR. WILLEM RUDOLFS, *New Jersey Agricultural Experiment Station:* In New Jersey we collect it and use it for a spray to kill mosquitoes.

Control of Odors*

BY WM. A. RYAN

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In an earlier period of our country's history, men settled near large waterways for two reasons: first, to be assured of an ample supply of water and, second, to have a convenient means of disposal of sewage by dilution. As the cities grew in population it was found to be necessary to avoid contaminating the source of water supply. Even today many cities continue to allow sewage to flow into waterways untreated and thus make a disposal plant of their rivers and lakes. It is fortunate that some of our citizens are sufficiently health-minded to spend large sums of money for the construction of sewage plants properly to treat the liquid wastes of the community.

A sewage plant may be designed to treat either straight domestic sewage or a combination of domestic and stormwater sewage. As the city or village increases in size and new industries locate therein, wastes of an industrial nature find their way into the city sewers. Home industries in the form of small breweries discharge quantities of wastes into the sewer which are extremely difficult to treat. It might be truthfully stated that odor control, like crime control, has become more difficult since the advent of the home brewery.

It is rather unusual for an industrial firm to build a treatment plant for improving the condition of its wastes unless official and legal pressure has been exerted. It is much easier and less expensive to allow the wastes to flow into the city sewers. During these days of economic depression the city official who will embarrass an industry to the extent of urging the construction of a suitable disposal plant is rare indeed.

It is little wonder that a multitude of conflicting, nauseating, penetrating and objectionable odors arise from sewage as it passes through the various units of the plant. As the poet might say "the sewage is treated but the odor lingers on."

Domestic sewage contains approximately 99.92% water and 0.08% solids. Of the solids 0.025 are in true or colloidal suspension and 0.055 in solution. The suspended matter is the only part of the sewage in which the operator is especially interested. When the great variety of matter which is carried along with the sewage is considered, there is little wonder that odors are produced which shock the olfactory nerves of the general public.

The compounds which make up a large percentage of the organic portion of suspended matter in sewage are proteins. Proteins are compounds of a complex structure containing five elements in varying propor-

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tions: carbon, nitrogen, oxygen, hydrogen and sulphur. There is one variety of protein which contains a small amount of phosphorus. The proteins may be classified as colloids. This may account for the colloidal nature of domestic sewage. The proteins in passing through the human system are mostly absorbed or broken down into smaller molecules to be passed out as food residue. Many forms of protein matter find their way into the sewage from culinary wastes, home brewery wastes, industrial wastes and other sources too numerous to mention.

The microörganisms, enzymes and inorganic compounds present in the sewage cause putrefaction to start as soon as the oxygen supply has been depleted. Putrefaction may yield a great variety of compounds, chief of which are amines, amino-acids, ammonia, hydrogen sulphide, volatile fatty acids, mercaptans, etc.

The amino acids possess unpleasant odors. The chief offenders in this class are indol, skatole, leucine, tyrosine and compounds containing phenol. The acid odor of sour milk, the rotten fish odor, as well as the glue-like odor of decomposing protein matter, the typical urine odor, as well as many other distinctive odors, are caused by bacteria and enzymes acting on protein matter.

Another class of compounds which give off odors of an offensive nature are the fats. These compounds contain but three elements: namely, carbon, hydrogen and oxygen. The chief odor-producing element, sulphur, is not present in fats.

Fats become rancid in two ways. The oxidation type of decomposition causes the fat to become rancid and to give off a tallowy odor; the hydrolytic type causes the fat to break down to fatty acids of a volatile nature such as acrylic, butyric, valeric, caproic, caprylic acids. These acids are sometimes spoken of as the goat acids. The name implies what odors one might expect.

The cellulose or fiber content of sewage does not cause an odor in itself but holds organic matter which gives off offensive odors.

The starches and sugars present are either oxidized or reduced without any appreciable odor.

Inorganic compounds present in solution or suspension which cause an odor are the sulphides and sulphates. These compounds are devoured by the sulphur-loving bacteria and one of the chief by-products of this diet in hydrogen sulphide. There is no need of swelling longer on this particular odoriferous compound as every one familiar with sewage is familiar with this gas and its destructive properties.

The question suggests itself, "can a sewage plant be operated in such a manner as to be entirely free from odor?" The answer to this question may be yes and no. What may constitute a nuisance to one person may not be offensive to another. It is quite doubtful if odor arising from the

average plant treating domestic sewage has been harmful to the health of an individual. It has caused discomfort to many people but the effect is apt to be psychological. In the case of a plant receiving a large percentage of industrial waste containing sulphur compounds, the amount of hydrogen sulphide given off may be sufficiently concentrated to constitute a health hazard.

In order to control the odors arising from sewage, disinfection plays a major part. The bacteria which reduce the larger molecules should be destroyed in part before the sewage enters the plant. The least expensive, as well as the most effective chemical for this purpose appears to be chlorine, or a compound containing available chlorine. Introducing the chlorine at a point upstream from the plant should eliminate odors caused by active bacteria. Chlorine may likewise combine with certain compounds such as hydrogen sulphide and the result of this reaction will be an inoffensive compound.

The operators' duties are not fully performed by disinfection alone. Cleanliness in every step of disposal is most important. The screenings from the rough rack and fine screens should be disposed of in a suitable manner.

Incineration is the most complete method of disposal of screenings. The one drawback to incineration is the heavy percentage of moisture in screenings. Through the addition of combustible waste, such as waste paper, screenings can be burned.

Another method of disposal is burial in a trench. This method is suitable for small plants but too expensive for the larger plants. If it becomes necessary to place screenings or scum in a pile for any period of time it is advisable to disinfect the mass to inhibit putrefaction. Bleaching powder is suitable for this purpose.

A third method of disposal is the separate digestion of the screenings and scum. We have experimented with this method in Rochester without marked success.

A liberal application of water by means of a hose is a great help in keeping the sides of channels and tanks free from grease and organic matter.

The methods by which odor may be controlled are not expensive although they involve a certain amount of work and some expenditure. The methods employed must be practical. The operator must keep in mind that the city or village officials desire the plant be kept clean, to function properly and to be free from odor. The taxpayer requires that the cost of operation be kept as low as possible. At least, this last statement is true today.

The embellishment of the plant grounds is a means of odor control. Through proper selection of trees and shrubs, such as pine, spruce, white cedar, larch, honeysuckle, etc., the plant grounds can be made so attractive that much of the odor from the plant will be masked.

There is a small sewage plant near a village west of Rochester. This plant has been in operation for twenty years. The tanks are shallow and troublesome wastes discharge into them. There is an offensive odor present at all times but the grounds are so well embellished with shrubs, pines, and nut-bearing hardwood trees that the people passing by on the highway scarcely notice the odor.

While the subject of embellishment is not closely associated with odor control, I will take the liberty of introducing at this time an idea that appeals to me. Instead of planting only coniferous trees around the plant grounds, it might be better to include more berry-bearing shrubs of the honeysuckle group and some nut trees. In this way the song birds and squirrels are attracted to the plant grounds as they have a food supply not found on the conifers.

Collecting and burning the gas from the slots is a great aid in odor control. There is likewise a fire hazard wherever gas is present. It is necessary either to prohibit or discourage smoking around a plant where gas is collected.

Glass covers over the sludge beds will confine the odor. Well digested sludge should not give off any offensive odors. Glass covers over the tanks have met with favor in some communities. This practice may help confine the odors, but I doubt if it will meet with general favor.

Summary.—Cleanliness about every part of the plant and grounds should be placed first in order of importance. Chlorine or bleaching powder may be considered as first aid to cleanliness. No scum, screenings or fresh sludge should be left around the grounds to putrify and attract flies.

Keep the digesting sludge in proper condition and a potential odor nuisance will be eliminated.

Shrubs and trees about the plant grounds tend to mask disagreeable odors during the spring and summer months.

Liberal use of water on the sides of the channels and tanks and any other place where organic matter is apt to lodge will be effective.

Foreign surface growths on sprinkling beds or contact beds should be removed or broken up. A liberal application or bleaching powder on the stones or sand will be found helpful.

A liberal use of light colored paint on hand rails and side walls of both operating house and tanks will prove of assistance in bringing lodged organic matter to the attention of the operator.

A careful study of conditions which prevail at your plant, a knowledge of the nature of the sewage, whether fresh or septic, and the kinds of industrial wastes which are present in the sewage, will help the operator to find the source of odors. Once the source is learned, proper means of elimination can be found.

Sewage a la Mode

BY MORRIS M. COHN

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Sewage is a by-product of life. Between man and man's wastes there stretches a bond as surely as there does between a manufacturing process and the product. Sewage has been defined as "water plus." That "plus" is the difference between water and sewage. Water exists without the presence of man. Into a new land, a virgin country, the pioneer sets foot and finds water in generous amounts. Not until he appears does sewage come into existence.

Even a committee on definitions, in an effort to define sewage in the required general terms, must indicate its human origin. Behind the "combination of liquid wastes conducted away from residences, business buildings and institutions, together with those from industrial establishments" stands the pulsing life housed in these structures.

The sewage flow reflects the life of the community. From the day that the first water-carried wastes went flowing through the first drain, until the present day of subconscious use of sanitary facilities, every change in living conditions has been reflected in the sewage flow. The sewage of today is not the sewage of a score of years ago, no more than our present habits of life are those of grandfather's time. Whether or not the mourner for the "good old days" fails to include the changes in sewage in his long list of things that aren't what they used to be, a change has, nevertheless, taken place. The discussion has been long and heated about the modern trends in sewage treatment. The shift from the septic tank with its elephantine scum-hide to the activated sludge plant, glass-overs 'n everything, has been accompanied by a change in the type of sewage that passes through treatment units. The modern devices are treating *sewage a la mode*.

There is one thing about sewage . . . it reflects the big changes as well as the trivial. The glorious rise in the standards of living, the sweeping revamping of the industrial world, the restrictions of a constitutional amendment, the pinch of depression—all are reflected fully as exactly as is the never-say-die spirit of the tomato seed.

Sewage Quantity a la Mode

In the Schenectady Sewage Pumping Station there are in use daily log sheets for recording station operation data. At the bottom of each sheet has been printed this succinct order: "Your Gages Tell the Story. Watch Them." The statement is correct and the order is well-advised.

The gages that record the flow entering a sewage works have a story to tell about how sewage flows mirror community life. The tale may be com-

plicated by many simultaneous changes, some of which completely cancel others. Howsoever, the changes are there, or should be there, by all the signs of the times. Here's how.

First of all, there has been a trend toward an increase in per capita flow, coming as a result of the increased use of water. The advanced standards of living have brought more hands, more often, to the water taps. The drains have worked overtime. In 1840 some one conceived the idea of fitting a bathtub with wheels and taking it from house to house for the cleansing of the community. Times have changed and the tenor sings in his tub and the water gurgles down the drain. Even after each proud family had its own tub, conditions were not conducive to the prolific use of water. The water was cold even after the steaming kettles were emptied into the tub—just as cold as the bathroom itself. It takes a Spartan to do more than swash dashes of water on an area of goose-flesh. In the toasty environs of the modern tile cubicle any cold-blooded citizen can blow like a porpoise and produce gallons on gallons of water plus.

Let us not forget that the injection of a water meter between the street main and the tap has offset somewhat the unthinking use of water. The net effect has been that increased flow has not become the distinguishing feature of present-day life.

Even if changes in total sewage flow have not been so marked, the rates of flow have done things to old traditions. Take for instance the Saturday Night Bath. Why, it was a national institution. When the family took turns in the tub, the water works must have had to throw in its stand-by pumps and the sewage works must have had to call out the reserves to handle the sudden peak. The Saturday Night Bath is no more. The morning shower for the bread-winner, the after-housecleaning bath for the housewife and the evening tub for the kiddies have smoothed off the high and low points of the flow curve and made tank detention periods more than a hollow sham.

The texts still show us typical flow curves for every day of the week and point out how even the uninitiated can distinguish Sunday by its late peak flow and Monday by its high wash-day load. It must be that modern living has turned these truths topsy-turvy. For example, late sleeping on Sunday morning is a thing of the past, now that the gentleman of the house turns out with the sun, showers, dons a pair of plus-fours and goes out to do battle with a wee white ball. He must have his pancakes and coffee so the kitchen sink goes into service early and disturbs the Sabbath peace of the sewage plant laborers. Then along comes the depression with its part-time working schedules. Early rising and seven o'clock flow peaks are no longer the order of the day. The whole flow structure crumbles and the flow analyst must look to the date in order to assure himself of the day covered by the Flow Record.

As for Monday washings, even this time-worn institution has gone into the discard. The back yard clothes line has disappeared from the fenceless lots and a revolving rack that has a capacity of a dozen handkerchiefs takes its place. The Monday morning conversations of the housewives no longer go on to the accompaniment of the squeaks of line pulleys. The commercial laundry has persistently advised the modern woman against the dangers of steamy kitchens and drafty clothes lines. They are doing a large percentage of the communities' washes despite the comforts of the electric home washers. The laundry truck knows no definite collection and delivery days. The washers, driers and mangles are as busy on Saturday as they are on Monday. The wash water that does enter the plant on Mondays is coming from the tubs of those ladies of older days who still cling to traditions.

Not only in the home has a change been made in the quantity of sewage produced. The industries have always centered about cities because of satisfactory transportation facilities, ready labor supplies and good market for their products. The industrial processes have required water in amounts varying directly with the rate of production. Boom conditions and depressions have left their mark on the sewage flows from the factories.

Nothing is too trivial to be considered in the analysis of flow fluctuations. When the big meal of the day came at noon and the evening repast was only supper, there must have been a dish water peak flow just after mid-day. Now that lunch consists of a snack at home or a hastily gulped luncheonette at the soda fountain, the peak comes after the evening dinner.

There must even be some sanitary significance in the argument of the dermatologists that the weaker sex are using cosmetics for skin cleansing instead of water. This tendency to desert the kitchen sink has, no doubt, been reflected in lower sewage production.

Every plant operator knows that there is much sewage dilution due to the use of water for improper purposes. In the poorer sections, winter nights find the water taps left running to prevent pipe freezing. In the summer, the water acts as the chilling agent in many a bathtub "refrigerator." The improved standards of living must have changed these conditions to some extent.

There may be other manners in which customs have changed the total production and rate of production of sewage. Some may be more concrete, not many can be more abstract than the ones already enumerated. What does it matter? The important thing is that there is such a thing as 1933 sewage flow characteristics.

Sewage Quality a la Mode

While quantity variations may distinguish present-day sewage flows from the flows that meandered through septic tanks of old, it is rather the quality

of the liquid wastes that lends significance to the term, "sewage a la mode."

There used to be a time when a plant operator could glance knowingly at his bar rack trash and tell what vegetables the housewife was canning. Not so today. The modern madam reaches into the drawer for a can-opener instead of going down to the cellar shelves for a jar of preserves. Somewhere, a plant in the canning country is having its treatment problems but the average works is relieved of much of the burden.

The use of all kinds of soaking, no-rub compounds for the home that still persists in doing its own washing, the use of sodas and ammonias for softening wash waters, the use of bath salts and reducing salts in milady's tub—all of these are adding to sewage materials that were foreign to the flow when yellow soap and good old elbow grease were the weapons of cleanliness. How many cans of scouring powder are used by the nation no one dares guess. However, with sixty per cent of the nation's population living in cities and towns and the average home using only two cans a week, some thirty million cans of partially insoluble grit would enter the sewers. With the kitchen grease as a bond, this material produces sewer clogging conditions which teach maintenance crews how to cuss.

In any survey of the modern habits that are producing changes in sewage quality, the ultra-modern use of mouth washes must not be overlooked. If the liquids have but a portion of the potency claimed for them, the dilutions in municipal sewage may yet reach antiseptic strengths.

There must be some truth in the report that sections of China make use of all human wastes for soil fertilization and that higher prices are paid for the wastes of the wealthy than for the sewage of the rice-eating coolie. Diet has much to do with sewage quality and the changed eating habits of today must be reflected in the evaporating dishes, Kjeldahl flasks and Sierp apparatus of the laboratory worker. It remains for some investigator to determine the difference in sewage quality during times of plenty and periods of low-earning power. The substitution of macaroni for potatoes, the replacement of beefsteak with stew, may be more than a problem for the calorie counters.

The home toilet bowl has always been the dumping spot for a motley array of household waste in no way associated with the sewage defined by any technical committee. Coffee grounds, egg shells, a used dish rag and everything else that won't go through the kitchen sink strainer have been thrown down the toilet and consigned to oblivion. The free collection of garbage and refuse by municipalities has, no doubt, destroyed some of the incentive for disposing of everything but the used baby carriage down the sewer. For this the bar rack attendant is duly grateful.

The home influences on changes in sewage character are interesting but trivial as compared with the impression industry has made. Domestic flows have been altered by a most puzzling array of manufacturing wastes.

There is everything from hair to acid to make the treatment problem complicated and to depopulate the best fishing streams. Tar in one city puts a complete tank of bacteria out of business while iron wastes in another produces chemical precipitation.

The effect of the motor age on sewage is no less distinct. The horse had no sanitary significance to the sewage expert—his wastes went to the back barn pile. The automobile is a vehicle of another color. It excretes from its understructure a mixture of spent oils and unspent gasolines. The sewage of the nation carries this objectionable mess on its surface. In the same category are the cleaning solvents that come from homes and cleaning and dyeing establishments. It is a non-progressive fuel company that is not selling cleaning fluids today.

And then along came prohibition. Suddenly the grain markets experienced a quickening of interest in their cereals and the raisin enjoyed a popularity not explained by its high iron content. The sewage works operator began to find spent mash in his grit, in his screenings and in his sludge. The toilet was a safer place to dump home-brew ingredients than was the garbage pail. The curse of prohibition does not end here. The dry agents come to town to mop up the oases and the sewers serve as the dump for the confiscated liquors. On many days, the flow is tinged a suspicious red and the digestive organisms at the plant grow gay. The new high test gasolines are colored. Likewise, the tinted sewage is "plus ethyl" if the alcohol used in the brew is of the ethyl group. . . .

You see, everything we do in the home and in the industry has its effect on the sewage flow. No custom is too trivial, no national event too great, to have its effect. It is not flowery to say that the chemist puts a bit of life into his test tube when he pours his sample of sewage. "Sewage a la mode" is more than a catchphrase. It is significant of the human side of the lowly liquids that a people produces. As life changes, so will sewage change. It may take a sympathetic eye and nose to see the variations. They may be intangible and abstract but the sewage plant experts are imaginative fellows, anyway.

Conditioning of Sludge in Separate Sludge Digestion Tanks

BY HARRY W. EUSTANCE

City Engineer, Ithaca, N. Y.

Plant operators who have separate sludge digestion tanks are indeed a fortunate class because of the fact that conditioning sludge is not a perpetual chore and a matter of every-day attention. You finally get the tank in condition, by dint of liming, recirculating and excessive patience, and wonder of wonders, you have something—a digestion tank working as the engineer with his fingers crossed has told you it would.

And what satisfaction. What a relief to our operating staff at Ithaca. Their greatest trouble apparently over. They concern themselves now with drawing, drying and disposing of excellent sludge, instead of worrying over the unknown physical force that in Ithaca had reversed the law of gravity and made sludge go up rather than down. Up, and out through the manhole covers, over the roof and down the freshly seeded slopes of the digestion tank embankment.

Now for the history of the conquest. We started off with our brand new equipment, pumping fresh sludge from the clarifiers at an increasing rate, according to a formula from 1-inch depth a day until we had nearly a 7-foot depth in the tank.

Not too good acting sludge, as our recollection goes, very acid and with an incipient interest toward foaming.

Then the catastrophe! The load on the mechanism gradually raised, and raised, until the Dorr safety apparatus threw itself out. What to do, drain the tank? Lose all the sludge we hoped to condition? Not, said the engineer, without making one attempt to break loose the disturbance and get the apparatus running again. So, with the operator protesting, he threw in the switch—grind, crash—and an order to Dorr for a big top spider shipped all the way from Denver.

Then we drew out the sludge, storing it in two old septic tanks reserved for the purpose. Repairs made, we returned the sludge to a tank full of warm sewage, liming by shoveling directly into the digester, after a barrel test for the amount of lime we thought needed to overcome the acidity we thought we had to remove.

Evidently an error was made in computing the amount. We got in too much, for the sludge, instead of having a pH of 7 as figured, went so high our comparator wouldn't record it. And trouble! A very heavy sludge, full of undissolved old lime at the bottom of the tank, so heavy a load it

* *Presented at the Fall Meeting of the New York State Sewage Works Association, Saranac Lake, October 14–15, 1932.*

again stopped the mechanism. This time the engineer wasn't called, the operators withdrew the sludge and consigned it eventually to the city dump *via* the septic tanks. (Just an interesting comment on this sludge stored in the open septic tanks—the sludge from a pH above 8, rapidly went acid, going down to 6, with no odor whatever, and when finally pumped to the dump no odor resulted there.) It didn't, however, have the characteristic digested appearance of the excellent sludge we have been drawing lately from the digestion tank.

Now for a fresh start with fresh sludge and with fresh tactics, and with perilously slow results.

(The different tactics.) Into the tanks of warm sewage we slowly added the fresh sludge, testing the pH of the fresh sludge and the mixture in the digester. The fresh sludge was around 7, but once entering the tank it dropped. Lime additions were made to the fresh sludge in the sludge well, calculated to raise the pH of the measured volume in the digester. No more lime was shoveled into the digester. The addition was made in two ways—at first we would put the computed quantity of lime in a tilted barrel, and let a hose wash the milk of lime into the pit as the pit filled with fresh sludge. Later we pre-mixed the water and lime and poured it into the pit before drawing fresh sludge and let it mix with the incoming sludge. Meanwhile the sludge was recirculated 3 or 4 hours a day and a pH of 6.6 or 6.8 was the best we could keep in the digester.

Then trouble came upon us. One week we had 6 ft. of good appearing sludge at the bottom of the tank, the next all at the top hugging the roof, and did it effervesce! Up and out! Foaming had begun. And with it an unprecedented flow of gas—30 to 40 thousand cu. ft. per day. The operator amused his perplexed self by putting samples of the sludge (from the top, of course) into Imhoff cones. It settled, then rose, with no justice, no reason. How to invert the proposition?

During the foaming period the overflow drooled sludge constantly, which returned to the clarifiers, adding nearly 50 per cent to the amount of sludge collected in the clarifiers and returned to the digester.

To cure the trouble we sought advice, and finally followed the adviser who said, "Try resting the tank." We did for ten days. No fresh sludge was added and foaming slowly stopped. Being optimistic and resolved to get the sludge conditioned, we started again, recirculating daily, and adding lime. The foaming repeated; still all sludge was at the top. We voted a longer rest—two weeks. Something happened. Gradually the foaming stopped, gradually the sludge settled from the top. In a do-or-die spirit we started again. No foam. Wonders! But a new menace. Scum! This scum was a heavy, hairy mass which clung to the scum arms and roped itself around it and eventually stopped the mechanisms by the pressure on the roof. Oh, my! Unload the digester again, start all this

war over again. We were discouraged, for then we didn't know the trouble. We drew down a couple of feet and saw the ropes. We were relieved. We would scrape off the scum, and so we did weekly for three or four months, sometimes two or three Ford truck loads, and all this queer hairy mass. Would it never stop? It did! Why? I don't know. Maybe a phase of the moon. Maybe because the operator decided to try a lower temperature and brought it down from 90 to 85.

That was the end of the war, the final surrender—conditional. How or why, what was the treatment, could it be repeated? We wouldn't expect rewards for any advice we could give.

But the tank is conditioned, the pH stays a perfect 7, no foaming, no scum, no hair. And the sludge is fine, reduced in moisture content from 97 to 93. It dries rapidly and without suggestion of odor. Visitors are now welcome! The operator goes around with a big grin, thinking that "Happy days are here again."

Correction—Mid-West Incinerator Corporation

In the discussion of the paper by A. B. Cameron, "Erie Sewage Treatment Works," page 813 of the September, 1932, issue of THIS JOURNAL, Mr. Cameron was asked what type of incinerator was used for burning screenings. He replied "A Mid-West Incinerator. This company has gone out of business." The reported demise was, however, as in the case of Mark Twain's death, greatly exaggerated. The Mid-West Corporation is still doing business at 105 West Monroe St., Chicago, and has not gone out of business. Mr. Cameron was misinformed by the contractors on the plant.

The Conditioning of Sludge in the Separate Digester, Fairport, N. Y.*

BY F. ARTHUR CARY

Supt. of Public Works, Fairport, N. Y.

The village of Fairport, with a population of 4800, is located in eastern Monroe County near Rochester, New York. Fairport operates its own electric light and water plants at a profit.

In 1913 fourteen acres of land were purchased by the village of Fairport, and a $6500 sewage treatment plant was immediately erected on the site. The plant consisted of a set of grit chambers, a sedimentation tank and sludge drying beds. During the summer months of 1928 and 1929 the State Department of Health advised that the effluent from these units be chlorinated.

In 1929 the village appropriated $77,500 for the remodeling and enlargement of its treatment plant. Trickling filters were constructed, a final settling tank was built, and last, but not least, a separate sludge digester erected.

The sludge digester is thirty-eight feet in diameter, with a cone-shaped bottom. The tank extends nine feet below ground level, and thirteen feet into the air. No means were provided for stirring or agitating the sludge within the digester. A four-foot square steel gas dome is in the center of the top. The supernatant liquor drains to the sludge drying beds. This caused odors in the summer, and in the winter transformed the drying beds into ponds of ice. After the first winter, the liquor line was changed, so that the supernatant liquor was discharged into the incoming raw sewage.

A Marlow piston pump with a capacity of 4800 gallons per hour was installed on the top of the digester, so placed as to pump the sludge from the bottom of the middle of the tank, forcing it out at the top of the digester about ten feet from the center. A brick house was constructed to house the pump, and it was found to be large enough for a small laboratory. When chemicals are added to condition the sludge, the pump is invaluable for mixing.

After starting the new plant in 1930, it was discovered that the sewage contained industrial wastes from two sources, one of which was quickly eliminated. An effort was made to treat the other industrial waste at the plant, but without success. Time after time the sludge was conditioned, using soda ash, lime and ammonia, bringing the pH up to as high as 7.6 to 7.8, only to see it drop back in the course of a few days to 6.6, 5.6 to 5.0, or even lower.

* *Presented at the Fall Meeting of the New York State Sewage Works Association, Saranac Lake, October 14–15, 1932.*

Last spring, with the help of Mr. Agar of the State Department of Health and the fine coöperation of the officials of the Certo Company, this waste was entirely removed from the sewer system.

After the elimination of the industrial waste early in May, all but eight feet of the sludge in the digester was drawn off. The remaining sludge was treated with milk of lime and well mixed with the aid of the sludge mixing pump. Since that time small amounts of lime have been added two or three times a week to the sludge in the digester. Ripe sludge was also added four different times for seeding. A very slow but constant improvement in the condition of the sludge has been noticeable throughout the summer.

A study of the temperature inside the digester was begun the first of August. A very slow rise in temperature within the digester continued during August and until September 30, when it was 62° F. This is undoubtedly the highest temperature for the year.

Recently about four feet of sludge has come to the top of the digester. This sludge is very dark gray in color, fluffy and porous in appearance. A large amount of gas is formed, which passes into the air. Small amounts of sludge are drawn from the digester to the drying beds each time fresh solids are added, on account of this floating mass of sludge. The sludge, once on the drying beds, seems to dry readily in spite of the fact that it is not completely digested.

Since May of this year there has been a slow, steady improvement in the condition of the sludge in Fairport's separate digester. The sludge moisture is being reduced gradually. The pH value is slowly climbing. The odor has been substantially reduced. The color or the sludge is becoming darker and darker.

As the other units of the Fairport plant are doing their work well in treating some 350,000 gallons of sewage daily, the fall finds us expecting that at last our separate digester will pour forth digested sludge.

Insect Control at Sewage Plants*

BY WILLIAM J. SIMPSON

Supervisor of Sewage Plants, City of Reading, Pennsylvania

Of the many problems with which the sewage works operator is confronted, perhaps the one which is most annoying is that one pertaining to insect control. This problem is annoying not only because the operator and his men are subject to the physical discomforts which accompany the presence of millions of insects traveling through the air, but also because there seems to be no positive method for destroying the flies. Further annoyance is caused by complaints and criticisms originating from those who reside in the neighborhood of the plant.

This paper is presented for the purpose of arousing some interest in, and discussion of, insect control. If the operators of various plants throughout the country do their little bit in studying this problem, there will, no doubt, be many good ideas advanced which may eventually lead to the complete eradication of this nuisance.

The insects particularly common to sewage plants and which cause the most trouble are the filter flies, *psychoda alternata*, and the mosquitoes. The former, by far the predominating nuisance, will be discussed first:

A study of the habits of *psychoda alternata* reveal that they will generally be found around sewage plants of all kinds, but are most commonly associated with trickling filter plants, from which their common name (filter fly) is derived. Investigation[1] has shown that these flies pass through a cycle of life which in the summer months is completed in about two weeks. The *psychoda* are hatched from eggs and pass into the larval stage. From this they are transformed into the pupal stage and later mature as the adult filter fly. The eggs are laid and hatched in the film on the stones in the bed. The film is also the harbor and feeding place of the insects while in the larval and pupal stage. The adult flies do not remain on the stone and film, but are found everywhere around the plant. While they are most numerous in the immediate vicinity of the filter beds they have been known to migrate a mile or more, when aided by a strong wind.

Control of *psychoda alternata* depends to a certain extent, on the construction of the filter beds, the efficiency of the clarifier, the load placed on the beds, the maintenance of surrounding grounds and upon geographical conditions.

Reports of investigators indicate that the most complete destruction of filter flies has been accomplished by flooding the beds. The ability to do this, of course, depends upon whether the beds are constructed to hold a flooding volume of water for periods of, at least, twenty-four hours.

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There must also be available sufficient filter area to take care of the volume of sewage diverted from the flooded section. This method is effective for only a few days and must be repeated.

Chemical control has been tried in many different ways but it must be admitted, with little success. Perhaps the most successful chemicals have been liquid chlorine and hypochlorite of lime. It has been contended by some that these chemicals have resulted in a small measure of success by sloughing off some of the gelatinous film and carrying the larvae with it.

The effectiveness of the above-mentioned chemicals is limited to the attack upon the larvae and they have no effect upon the adult flies other than retarding their multiplication for a short time.

Unfortunately, due to the danger of destroying the film and organisms in the bed, which are essential for proper nitrification of the sewage effluent, it is at the present time impossible to apply any chemical or insecticide of sufficient toxic strength to destroy the adult *psychoda* on the beds. However, the adult fly can be attacked off the bed and on surrounding structures by spraying with different solutions.

Perhaps the most common spray used for this purpose is kerosene, alone or in conjunction with orthodichlorbenzene, or different arsenate preparations. The writer's experience has been that, while kerosene alone is not particularly destructive to the fly, it does not evaporate so rapidly and as long as there is any remaining on the structures sprayed the flies endeavor to avoid it. Kerosene, even though it is not particularly toxic, can be recommended as a fairly good spray. Its inexpensiveness is a factor to be taken into consideration. Kerosene with from 25 to 50 per cent orthodichlorbenzene makes a deadly spray and its effectiveness will last for several days.

At Reading, Pennsylvania, while there was an overloaded septic tank in use, which discharged an effluent high in suspended solids, the *psychoda* were noticed in far greater numbers than since the operation of an efficient clarifier. During the use of the septic tank there were veritable clouds of flies, which have been reduced greatly by better clarification.

This tends to prove that heavier organic loads applied to the filters will also increase the *psychoda* population. Hence, it is up to the sewage works operator to attain the highest point of efficiency from the clarifier as a measure of control.

Proper maintenance and care of the sewage works grounds is also a great aid in controlling the filter fly. Any one who has had experience in walking through tall grass and weeds around a filter bed cannot help but realize that this growth makes a splendid resting place for insects.

It has been the thought of the writer that where complaints are received from inhabitants some distance from sewage plants of annoyance from filter flies, a barrier of tall growing trees, such as the lombardy poplar,

might be an aid. Since the migration of the flies to any great distance is accomplished by the aid of the wind, it appears as though this idea would be of some practical value. One thing should be strongly considered before any such barrier be planted, that is, the possibility of the root system of such trees interfering with pipe lines. Both for effectiveness as a barrier and to guard against endangering pipe lines and structures, the planting should be kept back at least 100 feet. Should a plant be surrounded by hills or forests, such a barrier, of course, would be unnecessary.

At many plants considerable trouble is experienced with the mosquito. This will be found to be particularly true where there are bodies of still water in the vicinity of the plant. In many cases, the control of the mosquito will be accomplished along with the *psychoda* control. Kerosene poured on stagnant bodies of water will serve as a good destructive agent in eliminating the mosquito and its breeding places. In spraying walls filter galleries and structures, it will be found that many mosquitoes are destroyed along with the *psychoda*. Closely mowed grass and weeds are also advantageous.

In conclusion, it is unfortunate that there is no positive method that can be recommended for the complete eradication of the most annoying insects at sewage plants. However, some suggestions have been made which will probably relieve this nuisance to a certain extent.

Where the flooding method of control is available, this appears to be the best in the light of present-day knowledge. Much relief can be obtained by good sewage plant operation, which certainly includes obtaining maximum efficiency from the clarifying unit. Maintaining the sewage works grounds in the best possible condition will do much toward the destruction of roosting places of both *psychoda* and mosquito. Spraying structures at least weekly, with kerosene alone or kerosene combined with some suitable insecticide, will kill great numbers of the insects.

Each plant operator, where the time and funds are available, can certainly help the problem of insect control by studying his own plant conditions and applying whatever relief measures may be adaptable to his plant.

It is suggested that a careful record be maintained of any control measures used and of the results.

References

[1] William W. Frye with Max Levine and E. R. Becker, "The Effects of Some Insecticides on the Psychoda Alternata," THIS JOURNAL, **3**, 345–6 (July, 1931).

Maintenance and Operation of the Sewer System and Sewage Treatment Plant and Methods of Financing West Long Beach Sewer District, Atlantic Beach, New York*

BY GEORGE NESBIT

Superintendent of Sewers, Atlantic Beach, N. Y.

The West Long Beach Sewer District, located on the westerly end of Long Beach, serves the unincorporated areas known as Atlantic Beach and Scheer Beach. This entire area up to 1926 was made up of sand dunes and low-lying meadow land. At this time private interests began the development of this land by the filling in with sand, dredged from the East Rockaway Inlet, to a uniform elevation of approximately 12 feet above low water. Other improvements quickly followed, and in 1927 the first houses were constructed.

Atlantic Beach has had a phenomenal growth, from an estimated population in 1928 of 1000, to 5000 in the summer of 1932. It has been highly restricted by the developing corporation, both as to the type of houses built and to recreational facilities. Hotels and bathing clubs are permitted in certain areas adjoining the board walk and ocean front. Residences are of Spanish or Moorish design in stucco, ranging from 8 to 15 rooms.

Water is furnished through the mains of a private water company, serving many Nassau County villages. They secure their water from deep artesian wells, aerated and treated before discharged into the mains. According to figures available, it is estimated that the water consumption in the District is 80 gal. per capita per day.

The sewage treatment plant, together with about 8 miles of mains and laterals, was built and placed in service in 1927 to serve an existing population of some 500. In 1930, the residents of Atlantic Beach petitioned the Town Board to create a sewer district, and to purchase the existing system for the sum of $321,000. After the District was established and the commissioners appointed by the town board, it became necessary to extend the then present sewer system to the easterly portion of the District, known as Scheer Beach, where 310 houses were then built. The extension of this system called for the laying of 9 miles of mains and laterals, bringing the total amount of mains and laterals to 17 miles at the present time; comprising 13 miles of 8-inch and 2 miles of 15-inch sub-mains, and 2 miles of 20-inch trunk. It is estimated that these sewers will be sufficiently large for at least 20 years. The present population reaches

* *Presented at the Fall Meeting of the New York State Sewage Works Association, Saranac Lake, October 14–15, 1932.*

a maximum of 5000 during the months of June to October, decreasing to 1500 for the balance of the year. Infiltration is negligible, as extreme care was taken at the time sewer lines were laid. The ground water level averages 9 feet below the surface of the ground.

From the most distant point served by sewer lines to the treatment plant is about three miles, which necessitates the use of three sewage lift or booster stations, each separated by a distance of one mile. These stations are composed of two 5000-gallon tanks with two vertical centrifugal pumps of 450 gal. per min. capacity each, which automatically discharge the contents of the tanks when the incoming sewage reaches an established level. Due to a scattered population over a wide area, and the period of time between pumping, considerable trouble was experienced in the two most distant stations. The sewage became septic, causing a heavy scum formation on the surface which had to be skimmed daily. Heavy sludge deposits on the bottom made it difficult for the pumps to operate efficiently. Extreme temperatures developed inside each station due to the lack of ventilation and the glass roof. Room temperatures ranged from 90° to 120° F. Water mains, during the summer months, were available so that by frequent flushings and dilutions a large amount of trouble was avoided. Our chlorine demand at the treatment plant increased from 8 to 25 p. p. m. It was then decided to experiment with lime treatment, and to decrease the time between pumpings to a minimum period. This was successful in keeping the sewage fairly fresh, and lowered the chlorine demand to 12–15 p. p. m. Odors were largely controlled, and pump troubles vanished when sludge deposits no longer collected on the bottom of tanks. Future plans call for the ventilation of the stations by the method used in several New Jersey plants, that of using the hollow flag pole with forced draft and passing the gases through a carbon or coke tower.

The sewerage system in Atlantic Beach is one of the few in the state with the ocean available for disposal of the effluent. This makes it possible to dispense with a great number of problems peculiar to interior systems which have inland waterways for disposal of the effluent. Our primary purpose of sterilization is for the protection of bathing beaches and shellfish areas. Prior to 1930, not much success could be claimed toward the operation of the treatment plant. Built in 1927, it consists of a plain settling or sedimentation tank of 68,200 gallons capacity. The effluent from this tank flows into the pump well of similar size. A dry well with two vertical centrifugal pumps, each capable of pumping at the rate of 850 gal. per min., discharges into a force main, where the effluent is chlorinated before discharge into the ocean. A small centrifugal pump, operated by a gasoline engine, is for emergency use and also for the pumping of sludge from the settling tank. Upon the acquisition of the plant by

the District, many changes were made to place the plant in efficient working order, as originally designed—the proper placing of baffles in the sedimentation tank, bar screen on the influent channel and the construction of manholes admitting air and light into both tanks. These tanks are underground with 10 feet of cover. Provisions were made at the time of construction for two additional tanks to be built when the capacity of the existing tank was reached. At the present rate of flow, incoming sewage has a detention period of four hours. Our plant has been taxed to full capacity at times during the past three months and in all probability we will be compelled to build additional tanks in the near future.

The original equipment included a manually operated chlorinator, which by reason of the increased sewage when the system was extended was ineffective to sterilize the effluent properly. This was replaced by a semi-automatic solution feed chlorinator of sufficient capacity to care for future expansion. This also was an economy in operation as it made it possible to dispense with several operators employed solely to control the old machine. As previously stated, the chlorine demand varied greatly throughout the day. In order to maintain a residual of 0.5 p. p. m. free chlorine at all times, it was necessary to change the machine setting five times daily. During the months of July and August, the sewage flow amounted to 500,000 gallons per day. The peak of the chlorine demand occurred from 12:00 noon to 6:00 P.M., at which time it was necessary to give a dosage of 25 p. p. m. Low water pressure at times caused difficulty in the efficient operation of the chlorinator. By replacing old water lines and the local water company checking and cleaning their mains feeding the plant, pressure was increased some 10 pounds, which solved that problem. The sludge in the sedimentation tank is pumped directly into the ocean during the winter months, when no damage could be done. Chlorination ceases from November to April.

Several years ago during a severe storm at sea, 1200 feet of the outfall line were lost. This was replaced by a new line, totaling some 2000 feet. After this was in operation a short period of time, shifting ocean beds broke the line. At the present time, the outfall projects into the ocean lashed to a jetty 400 feet long, as a temporary measure. The United States Government has under construction a huge breakwater extending from the extreme westerly point of Atlantic Beach, which will ultimately project into the ocean 8000 feet. When this is completed, it is planned to extend our outfall into the ocean, parallel to the breakwater for its entire distance.

A well-equipped laboratory is maintained for daily bacteriological tests. It was noted that when the new chlorinator was placed into service, residuals varied so that results were useless. The tap from which samples were taken was located about 20 feet from point of application, so a new

tap was made in the outfall about 300 feet away. This gave sufficient time for the chlorine to be well mixed with the effluent, and uniform residuals resulted. The percentage of settleable solids removed, as determined by Imhoff cones, averages 97.5 per cent. The pH is maintained in both tanks at about 7.0 by the utilization of lime treatment and the leakage of chlorine through the air relief line of the chlorinator. Due to the lack of space in the treatment plant, our combined laboratory and office is located some distance away, but plans call for its removal to the plant in the near future. *B. coli* tests of the chlorinated effluent and of the beach waters are conducted daily, with satisfactory results.

The sewage is entirely domestic, a part of which is septic. The population of the district is 5000, the sewage flow being 500,000 gal. per day from June to July and 150,000 the rest of the year. Chlorine applied is 72 pounds per million gallons. The average residual chlorine in the effluent is 0.5 p. p. m. The suspended material removed by 2-hour settling in Imhoff cones averaged 97.5 per cent. The pH of both the influent and effluent averaged 7.1.

Mention has already been made as to the original purchase price of $321,000. When it became necessary to extend the system, bonds in the amount of $207,000 were sold to pay for these improvements.

The duty then fell upon the sewer commissioners to formulate some plan of taxation whereby each parcel of land in the district would bear a proportionate share which that parcel derived from the operation and maintenance of the sewer system. It was determined that the only fair manner of taxation for our particular district would be that based on area, and not on lineal feet or assessed valuation. It was further determined that there should be a different classification between unsewered and sewered areas, as the law provides that in the future when a lateral should be built the property owners abutting thereon should bear the entire expense. This being so, the commissioners arrived at a difference of 10 cents per square foot allowance, and expect to maintain that difference until such times as they may deem that both areas are on an equal footing, at which time a uniform rate will prevail. The interest on bonds being fixed, the commissioners have no discretionary power, but the duty is imposed upon them simply to assess that amount upon the lands according to benefit.

The commissioners felt that the people using the sewers should stand the entire expense of their operation, actually adopting the principle used by all public utility companies in arriving at some plan whereby the people using the sewers pay only to the extent to which the sewers are used. In doing so they deem that a tax on the number of outlets on each piece of property would be a fair manner of arriving at that tax, there being situated in the district many small houses, apartment houses and hotels. A grad-

uated schedule is thereby made up, fixing a tax on the number of outlets on each piece of property. Rates adopted and in force for two years are as follows:

Outlets	Rate per year
1–10	$ 10
11–25	20
26–50	40
51–75	60
76–100	90
101–150	125
151–200	170
201–300	200
301–500	350
501–1000	500

For the year 1932, taxes for the interest on outstanding bonds and amortization amounted to twenty-six cents per 100 square feet in sewered areas, and fifteen and one-half cents in unsewered areas.

Difficulties in Winter Operation*

BY RALPH R. CLELAND

Engineer, Sewage Disposal Plant, State College, Pa.

Introduction

Of the many varieties of difficulties which confront the operator of a sewage treatment plant, those directly attributable to the elements are, without a doubt, among the most serious. A recently published article by Morris M. Cohn of Schenectady,[1] portrays very vividly and humorously the effect of temperature on plant functioning. The author describes the similarity of the ice on the trickling filter to the ice floes of the northern wastes through which a whaler steers its course, and tells of the hazards of making one's way on the ice-covered walks of Imhoff tanks when a terrific gale is sweeping across the landscape carrying with it clouds of finely divided snow capable of producing temporary blindness. He also speaks of the times when it was necessary to rub his ears with snow before dashing into the warmth of the office and of learning the trick of immersing his numbed fingers in warm sewage to prevent the agonies of frostbite. Those of us who have had similar experiences know these to be statements, not of exaggeration, but of fact.

Screen Chamber

There are very few units in a sewage plant that are immune to cold weather. Starting at the point of entry of the sewage to our plant, the screen chamber presents little, if any, difficulty. Because of the natural topography at State College the sewage is conveyed rapidly through the sewer system and in winter is quite warm as received at the plant. The screenings are placed in a wheelbarrow for measuring and there freeze into a solid mass which has to be heated before the barrow can be emptied. The application of a blow-torch on the bottom of the barrow remedies this difficulty very effectively. Other than this, nothing of an unusual nature is encountered.

Imhoff Tanks

The sewage, dividing at the screen chamber, flows through two Imhoff tanks which are quite susceptible to any change in temperature. To begin with, the temperature has a direct effect upon the subsiding value of suspended solids. At a temperature of 74° F., for example, the rate of settling is reported to be twice as great as at the freezing point.[2] Tests with Imhoff cones will show the tremendous load which is thrown onto

* *Presented before the Sixth Annual Conference of the Pennsylvania Sewage Works Association, June 23, 1932.*

the trickling filter, which in turn causes pooling and nozzle clogging. Little need be said concerning the effect of temperature on sludge digestion as it has been established that biological activity practically ceases below 45° F. and the solids in the tanks lie dormant until warmer weather arrives. To contrast the rate of digestion, it can be said that the time required for digestion can be approximately quartered by increasing the temperature from 56° to 77° F.[3]

There are several things that can be done to Imhoff tanks to overcome delayed digestion at low temperatures. Heating of the digestion compartment has not been successful, due to convection into the flowing-through chamber, resulting in low efficiency. It was our practice, up until the last two years, to wash lime into the gas vents with water from the city hydrant. The temperature of this water was considerably lower than that in the tank and its effect on digestion, particularly the gassing, could be readily observed. To remedy this situation we purchased a centrifugal pump, 70 g. p. m. capacity, mounted on wheels and driven by a gasoline engine. The three-inch suction hose of this pump can be placed in the warm sewage in the flowing-through compartment and this liquid used to hose the vents. In addition, the suction end is placed in the sludge compartment and the solids circulated until a thorough mixing is secured, thereby aiding digestion due to the seeding effect. We are of the opinion that sludge circulation is of prime importance in that it not only accomplishes a more intimate mixing of ripe and undigested solids but also relieves the tanks of excessive amounts of gas which are entrained in the sludge and which might later cause serious foaming.

The scum in the gas vents should be in such condition as to facilitate gassing, however little may be taking place. The past few winters in this locality have been very mild, with the exception of a few cold spells which were of short duration, and, consequently, the depth to which freezing took place was not great. Previous to that time, with temperatures from 10° to 20° F. below zero, the scum would be frozen for a thickness of several feet and, due to the pressure of the gas from beneath, the mass would be lifted from 12 to 18 inches above the freeboard of the tank. Obviously, such a condition results in harmful effects, especially in gas passing through the slots and carrying with it partly digested solids which will cover the flowing-through chamber. It is our practice whenever possible to remove the scum in the frozen state by cutting it into blocks and hauling it away. Between these intervals the scum is kept open by breaking holes through it with an iron bar or a wooden plunger. The freezing of scum in the gas vents presents a serious winter difficulty, particularly when it cannot be penetrated, as was the case at Schenectady two years ago when it was frozen solid and all attempts made to force holes through the mass proved unsuccessful.[4]

Foaming and its consequences can be said to be another winter difficulty since its most important cause can be blamed on the accumulation and inactivity of the sludge which, with an increase in temperature, begins to function like a six-day bicycle race. The only relief we have been able to find for foaming is to draw sludge from the tank. After this relief the sludge settles and behaves normally. Hosing has given temporary relief but adjustment of the reaction, none. We have had foaming at a pH of 6.5 and also at 7.5, likewise at every tenth interval between those two values. Our situation has been such that it was oftentimes impossible to draw sludge when foaming was occurring and there was nothing to be done except to allow it to proceed. Recent practice favors covering Imhoff tanks and, when possible, heating the enclosure with gas from the vents.

Dosing Tank and Trickling Filter

Passing from the Imhoff tanks, the sewage enters the siphon dosing chamber where the operation, at least in our plant, is independent of temperature change. However, the unit following this—namely, the trickling filter—causes much trouble during the winter, especially at night when the flow is low and temperature below zero. During the severe winter of 1917–18 it was our practice to turn off six of the eight rows of nozzles on the bed and allow the flow to be continuous through the remaining two rows. The laterals which had been turned off around 5:00 P.M., were drained into the pipe gallery and were again turned on when the operator began the following day's work. The results of this procedure were deplorable. To begin with, it was necessary to cover the entire collecting trough with a wooden frame upon which manure was heaped. This was required because the draining of the filter bed was a slow process and the small trickle in the underdrains would freeze solid after nightfall. When this occurred, it was necessary to heat iron bars in the furnace and drive them into the frozen drains before the flow could be resumed in the morning. If this was not done, applied sewage would flow laterally through the bed and would not only pass through the open rubble wall but would also run out of the two rows of underdrains which had been receiving the total flow during the night with such a force that the water would jump the collecting trough.

Trouble has been experienced with nozzle freezing and with pooling during the winter months. The former would occur at night when a nozzle would become clogged and the sewage in the riser would freeze solid to a depth of 12 inches below the spray cone. When this happened, the ice was removed by building a fire around the nozzle and sometimes by using a torch. Serious pooling has taken place during the past few winters because of the overloaded condition of the Imhoff tanks. In the writer's

opinion, the best way to remedy pooling is the application of chlorine. This method has been proved to be satisfactory throughout the country, particularly at Elgin, Illinois.[5] Here in January, 1930, the growth on the beds reached the extent that the stones were approximately 75% covered by the retained sewage. Chlorine was first applied to the night flow at the rate of 20.6 p. p. m. and this rate gradually decreased until the dose was 2 p. p. m. Within a period of a few weeks the stones were entirely freed from growth. There are, however, two disadvantages to this method; one is the expense involved, and the other is the sterilizing effect on the life in the filter. Regarding the cost, at the plant mentioned it was $237 per acre. This high figure is explained by the fact that the mat on the filter had been allowed to accumulate to a depth of 3 inches. The amount of chlorine required would have been considerably less had the work been begun at an earlier date. The action of the chlorine on the biological life in the filter can be readily understood. When a residual of 3 to 5 parts per million is maintained in the effluent, practically all life will have been destroyed and the filter will behave as it did when first placed in operation. This has been experienced at several plants in the east. The research work in biology being conducted on our open and closed filters has prohibited treatment of this nature and we have had to resort to picking over the stones on the top of the filter with a bar in order to loosen the film.

For reasons other than winter difficulties, we believe that trickling filters should be covered. Research at our plant has shown that a filter which is roofed over, so as to exclude light and the direct access of air to the surface, is not only slightly more efficient than the usual open type in removing bacteria and in oxidizing the sewage, but that the closed filter also possesses certain advantages in operation such as freedom from ice and snow during the winter, pooling due to algae growth, and, in summer, comparative freedom from nuisance due to *psychoda* and odors.[6] No accumulation of ice has been found in the closed bed at times when the open bed had ice to a depth of 18 to 24 inches. Cold weather has a deleterious effect on the biological life in a filter bed, particularly on the protozoa, the organisms responsible for an enormous bacterial reduction. Counts on these organisms have shown them to be more abundant in the closed than in the open bed.

Chlorination

Leaving the trickling filter, the sewage flows through the laboratory building at which point liquid chlorine is applied for disinfection. Our troubles with chlorine control apparatus disappeared two years ago when we purchased a new Wallace and Tiernan vacuum chlorinator. To prevent the formation of yellow ice known as chlorine hydrate, the room in

which the chlorinator is installed should be kept at a temperature between 50 and 70 degrees Fahrenheit. The apparatus should be kept at the same temperature or warmer than the chlorine container. For this purpose we have constructed a wooden box containing three 60 watt, 115 volt lamp bulbs and have placed it over the glass bell jar of the apparatus. The lighting of one bulb usually suffices to maintain the proper warmth. Operation in this manner prevents re-liquefaction of the chlorine in the apparatus, which frequently causes clogging in the pressure type of chlorine control equipment.

Secondary Sedimentation Basins

No difficulty has been experienced other than that of ice freezing on the surface of the secondary sedimentation tanks. The accumulation of ice has never been more than 2 inches in depth and we did not find it necessary to interfere except when the sludge was returned to the Imhoff tanks. At this time the ice would be broken and submerged to a depth at which it would melt. This procedure prevented clogging of the centrifugal pump.

Sludge Drying Beds

The problem of operating sludge drying beds during freezing weather has been one of our major difficulties. Open beds with a capacity of 0.5 sq. ft. per capita have proved wholly inadequate and have made it necessary for us to remove the sludge in the frozen condition. By observing the sludge daily after it has been drawn, it is possible to lift it when there is a perfect plane of cleavage with the sand. Our experience has been that less sand is lost at this time than is lost during the summer when the sludge is allowed to dry completely. Winter removal is satisfactory if, in the meantime, a heavy snowfall does not take place when the sludge is in a pasty condition thereby making it impossible to remove the snow and allow the sludge to freeze.

In order to drain the sludge more rapidly, a coagulant such as alum can be added. Good results are obtained when this chemical is applied at a rate of 2 to 6 pounds per cubic yard of sludge. The alum should be applied just before the sludge flows onto the beds so that the reaction is completed effectively without disturbing the floc.[7] The only real solution to the sludge drying problem is the installation of glass covers for the beds, which not only makes them more nearly independent of weather conditions but also reduces the area required by 50 per cent.

Conclusion

In conclusion it should be mentioned that much trouble can be eliminated by getting the plant in shape for winter operation. Draw the Imhoff

tanks as low as possible in the fall to provide storage space for sludge which cannot be drawn during cold weather. Clean and level the stones of the filter bed to prevent pooling. Recondition the sludge drying beds and, if possible, provide measures for lagooning or hauling away digested sludge. Last of all, secure the coal supply. The fact that the wind is howling and everything is freezing on the outside is no reason why the office or laboratory should not be comfortable.

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[5] E. E. Smith, "Control of Filter Growths by Chlorination," THIS JOURNAL, **2,** No. 3 (July, 1930).

[6] Elton D. Walker, "A Comparison of the Efficiencies of Open and Closed Trickling Filters," *Bulletin* **36,** Engineering Experiment Station, The Pennsylvania State College.

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Discussion

MR. C. C. AGAR: May I ask what the distribution system consists of; is it laid at the surface of the bed?

MR. R. R. CLELAND: Laterals laid on pillars of concrete.

MR. AGAR: How far from the surface?

MR. CLELAND: About three feet.

MR. AGAR: Do you have trouble with freezing?

MR. CLELAND: As I said the last few winters have been very mild. I have not experienced any but in looking back through the logs I find my predecessors had such difficulties.

MR. AGAR: Due to clogging of nozzles?

MR. CLELAND: Yes.

PROFESSOR ELTON D. WALKER, Pennsylvania State College: I was not here in 1917 and 1918 when we had severe conditions, but from conversations with people who were at the plant, and also from the records, freezing took place in some of the nozzles and in some risers for a short distance below the surface; also at the dead ends of the laterals which project through the masonry walls. After returning in 1919 we found that one or two of these laterals had been cracked by freezing which occurred at these dead ends.

Industrial Wastes and Stream Pollution

The Pollution of New York Harbor

A Study of the Relation Between Total Sewage Pollution and Resultant Harbor Condition as Influenced by Various Physical Factors

By Earle B. Phelps* and Clarence J. Velz**

Object and Scope

New York Harbor and its tributary waters drain a territory of some 14,400 square miles and must provide for the ultimate disposal of the wastes of some ten million people. In earlier times the vast resources of this waterway system available for such a purpose seemed practically unlimited. Even as late as 1912 it was seriously contended by Edlow W. Harrison, Expert Advisor to the Passaic Valley Sewerage Commission, that the Harbor waters alone could care for the sewage of a population of 60 million people, without the production of serious nuisance.

The investigations of the Metropolitan Sewerage Commission (1908–14), however, indicated clearly that there was an upper limit to the capacity of these waters to receive and dispose of human waste, and the evidence accumulated during the past two decades points to the conclusion that that limit is fixed somewhere in the region of existing populations and rates of increase reasonably projected into the near future. This evidence shows an increasing prevalence of local nuisances; a definite and continuous downward trend in the dissolved oxygen content of the Harbor waters as a whole; and the presence of areas of complete loss of oxygen, becoming more extensive and of more frequent occurrence with increasing population. At this time it may be taken as an assured fact upon which to base further investigations that the natural resources of the Harbor are now utilized nearly up to maximum capacity and that remedial measures of some sort must be taken if a condition of general nuisance throughout the Harbor is to be forestalled. We are still confronted, however, by certain questions which have never been adequately dealt with. What are the natural limitations of the Harbor waters expressed in terms of population and resulting harbor conditions; how much relief must be provided; when (with regard to population growth); and at what points?

* *Professor, Sanitary Science, DeLamar Institute of Public Health, Columbia University, Consultant in Sanitary Engineering, New York State Department of Health.*

** *Special Assistant Engineer, New York State Department of Health.*

Such questions of a quantitative nature cannot be answered, except by guess work, until there has been established a formula which will express in quantitative terms and in usable form the complex relationship which obviously must exist between contributing population and the effects of pollution upon the waters. Such a formula must take into account many physical factors such as volume of diluting water, distribution and movement of waters throughout the Harbor and its subdivisions, distribution of the population and sewer outfalls and re-aeration.

One such formula was proposed by Black and Phelps* in 1910 based upon knowledge then available as to contributing populations and their distribution, the circulation of waters within the Harbor and rivers and, in general, the value of the re-aeration factor. Computations of dissolved oxygen in various sections of the Harbor by means of this formula yielded results which agreed almost precisely with the experimental data published the following year by the Metropolitan Sewerage Commission, as indicated by the following table and explanatory remarks published in 1912.**

DISSOLVED OXYGEN IN NEW YORK HARBOR WATERS

A. Calculated by Black and Phelps, February, 1911
B. Analyses by Metropolitan Sewerage Commission for the Year 1911, Reported August 1, 1912

Location	Percentage of Saturation A	B
Lower Bay		
End of flood	100	100
End of ebb	71	74
Upper Bay		
End of flood	76	79
End of ebb	54	55–56
Hudson to 96th Street		
Ebb of flood	54	56
End of ebb	48	54
East River		
Mouth to Hell Gate		
End of flood	53	55
End of ebb	71	57
Hell Gate to Throggs Neck		
End of flood	71	57
End of ebb	81	86

"The computations refer to the areas indicated in the table, while the Commission's figures are necessarily for cross-sections. In each case the value for the area in question at the end of the flood is compared with the average figures for flood and ebb at the cross-section down-stream from

* Black and Phelps, Report Submitted to the Board of Estimate and Apportionment, New York City, 1911.

** Phelps, E. B., *Trans. Am. Soc. C. E.*, **76**, 1624 (1913).

the area in question, and at the end of the ebb with similar values for the cross-sections up-stream from the area in question. In the single case of the Hudson River at 96th Street at the end of the ebb there are no up-stream data available. The figure given is the average value for the ebb flow at the mouth of the Hudson. Obviously, the character of the water remaining in this section at the end of the ebb is worse than the average ebb flow, a fact which is indicated in the discrepancy of these two figures. With a single exception, the remaining figures show a striking agreement. There is evidently something wrong with our value at the region of Hell Gate, which has influenced the computed value of the ebb waters below Hell Gate and the flood waters above. It might be suggested that there is an influence of the Harlem River shown here which was not properly taken into account in our computation."

A recomputation made in 1919* in connection with the litigation then pending in the Supreme Court of the United States regarding the proposed discharge of the Passaic Valley sewer into New York Harbor indicated that the formula still agreed very closely with the general trend of conditions as measured in the Upper Bay, although failing to show reliably the conditions of the various subdivisions of the Harbor waters. These minor discrepancies were attributed at that time to a redistribution of the contributing population in the various sections of the greater city which had not been taken into account in the recomputation and which, as will be shown in this report, exerts a material influence.

This formula, however, developed a trend line depending only upon the increasing population, while the experimental observations, which have been made each year by the Board of Estimate, have shown not only a continuously downward trend of dissolved oxygen in the Harbor but also fluctuations above and below the trend line. These fluctuations are of such magnitude as frequently to obscure the general effect of the trend and, at times, to arouse false hopes in the minds of those charged with the important responsibility of protecting the waters against serious nuisance and at the same time of conserving the public funds. At the time of the litigation referred to, for example, it was seriously contended by competent observers that the downward trend which had been observed in the past had reached a condition of permanent equilibrium regardless of future growth of population. In fairness it should be said that this conclusion was reasonably justified by a study of the experimental data although entirely out of harmony with any reasonable theoretical consideration of the factors involved.

Mr. Wm. T. Carpenter,** who has been responsible for these analytical

* Ravenel, Mazyck P., "A Half Century of Public Health," N. Y. Amer. P. H. Assn., 1921.

** THIS JOURNAL, **2**, 276 (1930).

studies under the direction of the late Kenneth Allen, attempted at that time to derive some further correction factors to the general formula, with especial reference to the possible effects of precipitation. He elaborated his studies some years later, finding a certain degree of correlation between the dissolved oxygen in the Harbor waters in general during the summer months and the mean precipitation over the same period.

The physical factor relating the dissolved oxygen values to the general

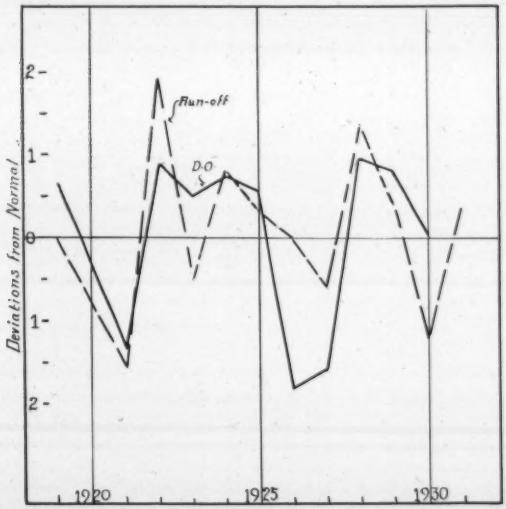


FIG. 1.—Relation Between Fluctuations in the Dissolved Oxygen of the Upper Bay in the Summer Run-Off of the Hudson River, 1919-30. The "Deviations from Normal" Are Expressed in Units of the Standard Deviation of the Variable.

rate of precipitation is obviously the run-off of the Hudson River. The significance of the river run-off in relation to the dissolved oxygen in the Harbor is well indicated in a preliminary determination of the correlation coefficient between the two over the period 1919-31. This coefficient is 0.6 ± 0.2. The actual relation is better shown in Figure 1. It is clear that, over this period at least, the run-off of the Hudson River exerted a considerable influence upon the Harbor conditions. A part of this influence is undoubtedly direct, due to the additional contribution of dissolved oxygen by way of the Hudson River. This influence was necessarily

evaluated by Black and Phelps but only in the form of a mean summer run-off. A second part, not previously recognized, is now found to be indirect through a relation which exists between the run-off of land water and the volume of new sea water which enters the Narrows at each flood tide.

At the present time, with the question of sewage treatment definitely before the city, the difficulty of interpreting the analytical results from year to year is increasing. This seems to be due largely to the fact that, as the depletion of the dissolved oxygen in the Harbor progresses, the system as a whole becomes more unstable and more subject to large fluctuations due to certain variable factors which have not hitherto been written into the equation. The purpose of the present study is to make a more complete analysis of the situation than has hitherto been attempted, with especial reference to the influence, direct and indirect, of the Hudson River, and the effect of shifting population centers, including the effect of partial sewage treatment before discharge. Finally, an attempt will be made, based upon the accumulated data of the past 21 years, to analyze the complex system of pollution, tidal circulation, re-aeration and self-purification existing in the Harbor, in an endeavor to arrive at a formula which will express the relation between any assumed extent and distribution of pollution, the run-off of the Hudson and the resultant condition of the Harbor. In this connection certain studies of the flow of the Hudson River with respect to its mean velocities from Troy to the sea have been made and, for the sake of completeness, the effect upon these waters of the sewage of the population within that stretch has been determined.

The Hudson River Run-Off

The summer run-off of the Hudson below Albany is controlled largely by impounding dams at Troy on the Hudson and at and above Cohoes on the Mohawk. The drainage area above these points is approximately 8000 sq. mi. out of a total of 13,500 sq. mi. at the mouth of the Hudson River and 14,400 sq. mi. at the Narrows. We have adopted as our measure of relative rate of run-off of the lower Hudson the sum of these two records without any attempt to include the additional run-off of lower tributaries.

No correction has been made for the water withdrawn from this area by the City of New York. The area of watershed involved has increased from about 375 sq. mi. in 1909 to 632 sq. mi. in 1930 (excluding the Schoharie drainage to the Mohawk) or from 2.7 per cent to 4.5 per cent of the total at the Battery, and the actual diversion from the summer run-off has been a variable part of the total.

The basic run-off data were obtained from the reports of the U. S.

TABLE I

MEAN MONTHLY AND TOTAL SUMMER MONTHS' DISCHARGE OF THE HUDSON RIVER AT MECHANICSVILLE AND OF THE MOHAWK RIVER AT COHOES AND OVER THE COMBINED AREA EXPRESSED IN C. F. S. PER SQUARE MILE

(Drainage Area above Mechanicsville, 4500 Sq. Mi. and above Cohoes, 3500)

		May			June			July			August		
Year	H. R.	Moh.	Tot.	H. R.	Moh.	Tot.	H. R.	Moh.	Tot.	H. R.	Moh.	Tot.	Total
1909	3.82	2.77	3.39	1.34	1.09	1.24	0.44	0.44	0.44	0.34	0.33	0.33	1.350
1910	2.09	1.67	1.92	2.27	2.03	2.17	0.36	0.39	0.37	0.44	0.52	0.48	1.235
1911	2.10	1.70	1.94	0.99	2.16	1.47	0.30	0.49	0.38	0.26	0.42	0.33	1.030
1912	2.87	2.49	2.71	1.23	1.10	1.18	0.29	0.43	0.35	0.28	0.48	0.36	1.050
1913	1.56	1.35	1.48	0.90	0.21	0.62	0.40	0.24	0.33	0.24	0.18	0.22	0.658
1914	2.87	2.12	2.56	0.52	0.34	0.45	0.48	0.90	0.65	0.32	0.89	0.56	1.050
1915	1.19	1.03	1.11	0.43	0.52	0.47	1.89	2.23	2.03	1.75	1.95	1.82	1.330
1916	2.89	2.56	2.75	1.53	1.54	1.54	0.87	0.91	0.89	0.38	0.51	0.43	1.400
1917	2.24	2.40	2.31	3.16	3.32	3.23	0.97	1.36	1.13	0.42	0.74	0.55	1.800
1918	2.33	1.66	2.05	1.08	1.05	1.07	0.51	0.72	0.60	0.33	0.38	0.35	1.015
1919	2.93	2.70	2.84	0.91	0.63	0.75	0.60	0.66	0.62	0.44	0.46	0.45	1.163
1920	2.12	1.56	1.89	0.74	0.80	0.76	0.58	0.54	0.57	0.59	0.64	0.61	0.958
1921	1.28	1.24	1.26	0.40	0.39	0.39	0.98	0.72	0.87	0.45	0.46	0.45	0.743
1922	2.51	1.59	2.14	2.62	3.15	2.84	1.28	1.06	1.19	0.69	0.88	0.77	1.732
1923	2.91	2.00	2.54	0.88	0.82	0.86	0.42	0.45	0.43	0.29	0.36	0.32	1.030
1924	4.51	3.32	4.01	0.81	0.70	0.76	0.45	0.52	0.48	0.42	0.45	0.43	1.420
1925	1.91	1.43	1.71	1.07	0.99	1.04	1.44	1.07	1.29	1.07	1.16	1.11	1.280
1926	2.96	1.83	2.50	1.26	0.94	1.12	0.70	0.59	0.66	0.56	0.72	0.62	1.230
1927	2.18	1.75	2.00	0.92	0.95	0.94	0.46	0.65	0.54	0.51	0.68	0.58	1.017
1928			2.35			1.75			1.36			0.90	1.591
1929			3.20			0.97			0.71			0.40	1.321
1930	1.48	1.04	1.29	1.42	0.59	1.06	0.69	0.41	0.57	0.54	0.25	0.42	0.832
1931	1.59	1.88	1.72	1.14	0.89	1.03	1.36	1.53	1.44	0.75	0.47	0.64	1.206
												Mean	1.19

Geological Survey. Table I shows the yield in c. f. s. per sq. mi.,* as recorded on the Hudson River at Mechanicsville, drainage area 4500 sq. mi; and on the Mohawk at Cohoes, drainage area 3500 sq. mi; from which is calculated the yield of the combined drainage area. It will be shown that the time of passage of water from Albany to New York Harbor during the summer months is approximately 30 days, so that the period May to August, which has been totaled to represent the summer run-off, corresponds approximately with the period June to September, during which most of the analytical work on the Harbor was completed.

Since the mean run-off over these summer periods and its variation from year to year exert, as we believe, an important influence upon the condition of New York Harbor and since, in any remedial program, it may be desirable to project certain assumed conditions into the future, the relative frequency of mean summer run-offs of less than stated magnitudes have been computed. Run-off values as low as 1.74, 1.19, 0.95 and 0.72 cu. ft. per sec. per sq. mi. or lower may be expected to occur during 96, 50, 20 and 5 summers per century and are referred to as the 96, 50, 20 and 5 per cent chance rates, respectively.

A study of the Upper Hudson from Albany to the New York City limits has been made with respect to the distribution and extent of sewage pollution by the various communities draining into the river, and especially with respect to the time of passage through this stretch and the resulting rate of biochemical oxidation and of subsequent re-aeration, in order to arrive at an approximate measure of the quality of the Hudson River water as it enters the lower district, with which we are particularly concerned.

A series of "Diagrams of Hourly Tide and Current Conditions in the Hudson River," kindly provided for us in advance of publication by Mr. O. B. Hertzog of the U. S. Coast and Geodetic Survey, show, among other details, the actual current strength in the channel at all points between New York and Troy and at each hour throughout a tidal period under mean tidal conditions and for summer months. From these it was possible to integrate the movement of a single particle passing Albany at any time and to take the median position of the resulting oscillating movements up- and down-stream as representing the velocity of a continuous stream flow. The use of channel velocities is believed to give the most nearly representative conditions for our present purpose, since the determining proportion of the total stream flow actually flows in the channel section. These velocity data provide the "time" column of Table II.

The Pollution of the Upper Hudson

In considering the pollution of the Upper Hudson it has been found expedient to group the various communities and assume that the resulting

* Cubic feet per second per square mile.

TABLE II

POLLUTION AND SELF-PURIFICATION OF THE UPPER HUDSON, 1930

	Station	Distance (Nautical Miles)	Time* (Days)	Population Equivalent (Thousands) Added	Remaining from Above	Total	Reaching N. Y. Harbor	Dilution Added, C. F. S.	Population Equivalent (Thousands) Utilized in Stretch	Remaining	From Dilution	Net Remaining
1.	Albany	113.4	37.0	226,500		226,500	45	3,750			862,500	862,500
2.	Hudson	88.9	31.0	20,300	58,000	78,300	13	470	168,500	694,000	108,200	802,200
3.	Kingston	67.4	27.0	29,700	30,500	60,200	50	730	47,800	754,400	167,800	922,200
4.	Poughkeepsie	53.4	23.3	40,300	26,000	66,300	185	80	34,200	888,000	18,400	906,400
5.	Newburg	40.7	18.8	38,000	23,200	61,200	470	225	43,100	863,300	51,700	915,000
6.	Peekskill	26.2	12.5	17,100	14,300	31,400	980	285	46,900	868,100	65,600	933,700
7.	Ossining	16.8	8.5	23,300	13,000	36,300	3,350	190	18,400	913,300	43,700	959,000
8.	Tarrytown	12.3	5.2	22,700	17,000	39,700	7,000	10	19,300	939,700	2,300	942,000
9.	Dobbs Ferry	8.3	3.3	17,700	25,600	43,300	8,000	20	14,100	927,900	4,600	932,500
10.	Yonkers	3.5	1.2	263,300	26,000	289,400	200,000	10	17,300	915,200	2,300	917,500
11.	Spuyten Duyvil	0	0	0	220,000	220,000		10	39,700	877,800	2,300	880,100
	Totals			570,300			220,093		449,300		1,329,400	

* Time of passage under flow of 0.442 c. f. s. per sq. mi.

pollution enters the river at 10 points beginning at Troy-Albany and ending at Yonkers, just above the New York City line. Populations have been taken as of 1930 and it has not been considered necessary to make any refinement of the crude population data either by reason of unsewered population or of partial treatments. The salient facts are shown in Table II.

The time and population values are combined by means of the known rate of biochemical oxidation, which, at summer temperatures, proceeds at 20.6 per cent in 24 hours, obtaining thereby the values "equivalent population remaining." By successively adding the new contributing population to that remaining from above the table is completed down to Spuyten Duyvil. It is interesting to note the extremely small residual

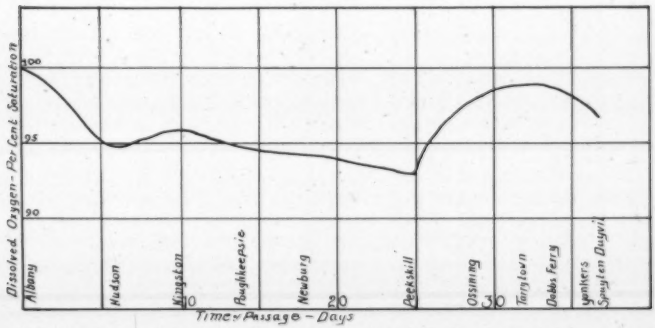


FIG. 2.—Dissolved Oxygen in Hudson River, Albany to New York, Computed from Theoretical Relation Between Mean August Run-Off, Population for 1930, and Re-aeration Constants as Determined on the Ohio River.

pollution that is carried past this point, the value being materially less than the actual contributing population at Yonkers, just above the city line. In the column "reaching New York Harbor" the actual residual populations measured at Spuyten Duyvil are placed opposite the points of their respective origins.

This large loss of B. O. D.* must be balanced by three factors, the increasing volume of the stream, a reduction in the D. O. of the river water and re-aeration. The effect of increasing volume is indicated in the column headed "dilution added," which is merely taken in proportion to the in-

* The expressions biochemical oxygen demand and dissolved oxygen recur so frequently in the text that they will be abbreviated in the forms quite commonly employed by sanitary chemists, B. O. D. and D. O.

crease in drainage area to the point in question and at the mean August value of the run-off, namely, 0.442 c. f. s. per sq. mi. This, it will be noted, is less even than the 5 per cent chance mean summer value, having been purposely taken to develop the maximum pollutional effect in this stretch. Since we are dealing in population units, it is necessary to convert these volume quantities into a population equivalent. This is done upon the basis of a daily contribution of 0.22 pounds of B. O. D. per capita and assuming that the new dilution water is saturated with D. O. Again subtracting at each station the population equivalent of the B. O. D. removal in the stretch above and at the same time adding the population equivalent of the new dilution water, we obtain the final column which gives the net population capacity of the water at each station. This is in fact the population which the stream at that point could care for by just exhausting its existing supply of D. O. Under August conditions the capacity of the stream is hardly altered between Albany and New York and upon its arrival at the upper city limits it has a greater capacity than the river of smaller stream flow had when passing Albany. As far as the Harbor is concerned, therefore, the flow of the Hudson River at Spuyten Duyvil may be considered to contain the sewage pollution resulting from a population of 220,000.

It is necessary to distinguish clearly between this assumed condition and the actual facts as observed upon the river. We have in actuality, at this point, a noticeable degree of pollution and of oxygen reduction due to the upward flow of polluted water from the lower section of the river. The stream which has been considered in the foregoing analysis is an hypothetical stream having a continuous down-stream movement in which there is no effect of pollutions further down-stream. Starting with such an hypothetical stream entering the city proper a study of the effect of the New York City pollution must take account of tidal oscillation and the mean time of passage through the Harbor waters. It has in fact been necessary to apply a certain correction to the pollution from Tarrytown down to allow for the effect of tidal oscillation.

We are now in position to determine the actual character of the Hudson River water, with particular reference to its D. O. content. An approximate computation has been made using a formula proposed by Streeter and Phelps* based upon the data of the Ohio River. The results are shown in Figure 2. While we do not place great reliance upon this result, we are of the opinion that it represents, within a sufficient degree of approximation, the actual facts, especially in so far as they relate to the condition of New York Harbor. Again it must be noted that thus far we deal with a continuously flowing stream and that for the region of the estuary, indicated by the presence of sea water, a further treat-

* U. S. Public Health Service, *Bulletin*, **146** (1924).

ment is necessary. The results therefore show merely the condition of the river as if unaffected by pollution from places down-stream.

The Flow of Sea Water Into New York Harbor

The total tidal flow through the Narrows into the Upper Bay is approximately 12 billion cubic feet per tide under mean tidal conditions. If this were pure sea water carrying its full quota of D. O. there would be no further question at the present time, or even in the distant future, of a limitation of the capacity of these waters to oxidize sewage. This however, is not the case. Owing to the configuration of the Lower Bay between the Narrows and Sandy Hook, there is a large reservoir into which the ebb waters from the Upper Bay discharge and from which the flood waters are drawn. It is necessary, therefore, to arrive at some measure of the amount of actual uncontaminated sea water which enters the Harbor during each flood tide. Black and Phelps determined this value from a study of the actual tidal volumes in various sections of the Bay and of the interchange of waters between these sections through a tidal cycle as determined by velocities and channel sections. It was estimated that, under mean tidal conditions and mean summer run-off of the Hudson, approximately 81 per cent of the flood waters through the Narrows was composed of water which had previously been in the Upper Bay and that the remaining 19 per cent represented new sea water with its full quota of D. O. The importance of correctly evaluating this quantity has suggested an independent determination based upon more complete analytical data now available and upon the following line of reasoning.

Under any condition of equilibrium between the land water discharge of the tributary rivers and the tidal circulation, it is obvious that the entire land water discharge for one tidal period must pass out through the Narrows on one ebb tide. With a fairly fixed value for the ebb flow it follows that there must be a fixed relation between the river run-off and the proportion of land water to sea water flowing through the Narrows on the ebb tide. This proportion of land water to sea water provides a basis for the determination of the proportion of the daily land water run-off which returns to the Harbor by way of the Narrows on the flood tide.

For example, if the ebb flow through the Narrows be 12 billion cu. ft. per tide and if this be one-third land water, then the ebb movement of land water during the same period will be 4 billion cu. ft. If during this time the run-off of the Hudson River be 0.8 billion cu. ft. then 3.2 billion cu. ft. of land water had come back on the previous flood tide. This is 80 per cent of that which went out on the ebb. Consequently this same proportion, 80 per cent, represents the sea water which is returning in the flood flow after having previously left the Harbor. The balance of

20 per cent of the flood sea water represents what may be termed new sea water entering the Harbor from the sea for the first time.

A curious and rather unexpected result follows the application of this formula for the volume of new sea water to the actual conditions. It appears that when the salinity at the Narrows is above 50 per cent, or thereabouts, an increasing land water run-off results in an increasing amount of new sea water being available for dilution. This condition results from the general topography of the Lower Bay which in its channel section has about the same capacity as the total flood flow from the Harbor. The amount of new sea water entering on the flood therefore is determined largely by the excess of the ebb over the flood flow, which in turn depends upon the Hudson River run-off. At river stages, seldom reached during summer months, producing a mixture at the Narrows of over 50 per cent land water, the reverse situation occurs as it does normally in a tidal estuary. Increasing land-water-run-off results in a decreasing flood flow of sea water.

The amount of sea water entering the Harbor with each tide is therefore a function of the Hudson River run-off, but we have thus far derived a quantitative measure of it only as a function of salinity values at the Narrows. It has been necessary therefore to make a comparison between such salinity observations as are available and the corresponding run-off figures for the Hudson River in order to determine what quantitative relation exists between these two factors and thereby ultimately to derive the relation between the Hudson River run-off and the sea water flow through the Narrows. A preliminary study of the correlation between the mean monthly run-off values for the year 1909 and a corresponding set of salinity observations made by the Metropolitan Sewerage Commission gives the correlation coefficient

$$r = 0.9 \pm 0.3$$

and a regression equation

$$Y = 9X + 22 \pm 3$$

in which Y is the proportion of land water at the Narrows through a tidal cycle expressed in per cent, and X is the river run-off in c. f. s. per sq. mi.

This purely empirical relation is reasonably satisfactory for the year in question but a study of the salinity data in the entire Harbor and river system has indicated a somewhat more fundamental and rational method of approaching the problem which gives not only a better determination of the relation desired but also a somewhat more complete and useful picture of the circulation of the tidal water throughout the various sections of the system.

The Salinity Gradient

Theoretically, two extreme assumptions may be made regarding the distribution of salt water in the Harbor and rivers. It may be assumed

on the one hand that waters entering the Upper Bay through the Narrows or by way of the Husdon or East River are quickly and uniformly mixed with the waters of the Bay and similarly for the other subdivisions of the Harbor. This was the tacit assumption made by Black and Phelps who subdivided the entire area into seven sections and dealt with each of these as a unit of uniform composition. The opposite extreme assumption would consider the movements of the various currents to be of a piston-like character without any degree of horizontal mixing.

A study of what may be termed the salinity gradient, meaning thereby the horizontal distribution of salinity along axes of flow, indicates clearly that the actual circulation of the waters within the Harbor results in a condition intermediate between these two extreme cases. The first assumption, for example, would yield an approximately uniform distribution of salinity in the Upper Bay and the second would result in a sharp dividing line with land water on one side and sea water on the other but without any intermingling. The salinity gradient actually observed is neither one nor the other of these but it does have certain characteristic and significant properties. With run-offs ranging from 0.45 to 4.97 c. f. s. per sq. mi. the gradient is quite uniform up to about 90 per cent of land water and flattens off slightly with higher percentages. Within the 90 per cent range, which makes a convenient range for these computations, it has an actual value of 2 per cent of sea water per nautical mile.

Obviously this salinity gradient must be reckoned with as a part of the hydraulic gradient in any consideration of stream run-off. The difference in specific gravity between sea water and land water taken in connection with the mean depth of the channel, approximately 32 ft., is equivalent to a hydraulic head of 0.96 ft. This difference in head would produce an equilibrium of pressures at the bottom but would result in an unstable condition at all lesser depths. Taking moments about a vertical plane representing a theoretical dam the condition of equilibrium of total pressure on the two sides of the dam is represented by a difference of 0.48 ft. This difference in hydraulic head will produce hydraulic equilibrium throughout the section as a whole but will leave unbalanced pressures by virtue of which salt water will flow up-stream on the bottom of the channel and fresh water down-stream on the top. Final total equilibrium is obtained only when the hydraulic head between a point of approximately 100 per cent land water and a corresponding point of 100 per cent sea water is equal to 0.48 ft., and when circulation and diffusion have resulted in a very slight vertical salinity gradient and in an up-river flow of sea water sufficient to maintain the horizontal gradient at the existing value.

In the river section, where the salinity gradient is 2 per cent per mile, the actual surface slope necessary for equilibrium is 0.0096 ft. per mile. This condition represents a momentary hydraulic equilibrium with no land

water flow. If, now, we superimpose a given river flow we have merely to add the necessary additional hydraulic gradient and a corresponding up-river flow of salt water of sufficient magnitude to maintain the salinity gradient previously established under static conditions. But this up-river flow of sea water is conditioned primarily upon tidal action and is approximately constant in quantity, at least to the extent of the constancy of the tides themselves. It follows therefore that with variable river flow and the constant salinity gradient observed experimentally, the actual elevation of the gradient line will rise and fall with the river flow. In brief we have the picture of a salinity gradient essentially constant in slope at all river stages maintaining the static equilibrium, but varying in its position up- and down-stream according to the relation between the varying land water flowing and the essentially constant tidal salt water movement.

The actual surface slope of the river under mean tidal conditions and without consideration of variations due to tidal elevation will consist of the salinity gradient just described plus the necessary hydraulic slope to provide for the river velocity. If it were possible to determine this slope with the necessary degree of precision over the entire range of run-off with which we must deal, it would become a comparatively simple matter to determine the upper limit of the salinity or any other convenient point, such as the position of 10 per cent salinity, for it is obvious that such a point will be located where its elevation above the level of the Bay is equal to the elevation due to the hydraulic slope plus that due to the salinity gradient. An attempt has been made to determine the necessary constants relating the river run-off and the hydraulic slope from certain precise data of the U. S. Army Engineers Office but the complicating tidal movements make it practically impossible to compute these with the necessary precision. This procedure, however, provided a fair approximation from which it has been possible to fit the observational data into an empirical equation.

Briefly, if we assume the equation,

$$Q = 415{,}000\sqrt{s}$$

in which s has its usual significance of hydraulic slope and then write

$$S = (Q/415{,}000)^2 + 0.0096 \qquad (1)$$

in which S represents the combined hydraulic and salinity gradients or the actual surface gradient of the stream, and if we take as our datum point for elevations and distances, the sea level at a point within a few miles of and below the Narrows, at which point the salinity is represented by 90 per cent sea water, then we may write

$$D = 0.38/S \qquad (2)$$

in which D is the distance in miles up-stream to the point at which the salinity is represented by 10 per cent sea water, 0.38 being the proportionate part (80 per cent), of the total difference in head required for equilibrium between fresh water and sea water. Similarly, the distance to a point of any other salinity will be given by

$$D_d = 0.48d/S \qquad (2a)$$

where d is the difference in the proportions of sea water at the two ends of the stretch, the lower end being at 90 per cent.

Returning now to the 1909 data the mean values of Q are 8780 and 39,400 for the high and low water groups of 7 and 5 month, respectively. By formula (1) and (2) the positions of the 10 per cent sea water points are 38 and 20.4 mi. up-stream from the hypothetical datum point of 90 per cent sea water. The actual salinity observations at the Narrows over these same periods averaged 76 per cent and 49 per cent sea water, from which we compute, on a salinity gradient of 2 per cent land water per mile, distances of 33 and 19½ miles, respectively, above the Narrows. This would indicate that the assumed datum point where the water contains 90 per cent of sea water is at 5 miles and 1 mile, respectively, below the Narrows. Since, as previously shown, the actual volume of undiluted sea water entering the Narrows on a flood tide increases with increasing river run-off, the approach of the 90 per cent sea water location toward the Narrows on the high run-off is at least consistent. To the extent that this assumed datum point is displaced by varying run-offs the location of the actual position of the upper 10 per cent point is indefinite but fortunately this results in an uncertainty of the salinity at the Narrows, toward which we are working, of only 2 per cent per mile of uncertainty in the location of the upper limit. The situation is improved considerably if the above computations, based upon a year's record in which the individual monthly values are quite concordant, are taken to be correct and the location of the datum point for any stream flow be determined by assuming a linear relation as fixed by this pair of corresponding values.

During the 7 months of low run-off the average salinity at Tarrytown, 30 miles above the Narrows, represents 23 per cent of sea water. This gives a distance by formula (2a) 32 miles above the 90 per cent datum point or 27 miles above the Narrows. The other 5 months' run-off gave a mean salinity value representing 16 per cent of sea water at Fort Washington Point, 15.5 miles above the Narrows. The distance computed by formula (2a) is 19 miles above the 90 per cent datum or 18 miles above the Narrows. While these formulas, like the regression equation previously derived, are based upon the records of a single 12 months, they are worthy of greater confidence because of the more fundamental character of their derivation. They are, in fact, rational expressions of a set

of physical conditions in which the numerical constants only, not the form of the equation, are determined by observational data.

Briefly then it is proposed to compute by these formulas the approximate distance up-river of the point at which the river carries 90 per cent of land water. The composition of the water at the Narrows is then determined by deducting land water at the rate of 2 per cent per mile over this distance.

The ebb flow through the Narrows is taken as one-half the sum of the mean flood and ebb flows, as determined by the Coast and Geodetic Survey over a period of years, plus the 6.5-hour run-off of the Hudson for the month in question. The total amount of land water passing the Narrows on the ebb is the product of the ebb flow by the percentage of land water. This is made up of the flow of the Hudson plus the land water which had returned on the previous flood. The ratio of the amount returning to the amount leaving is taken as the ratio of the amount of all the Harbor water returning a second, or later time, to the amount leaving on any ebb. From this is derived directly the amount of new sea water entering on any flood tide. Figure 3, plotted from the data of Table III, shows the final relation derived between the Hudson River run-off and the quantity of new sea water returning each day. With a mean summer run-off of the Hudson of 17,000 c. f. s. the incoming new sea water is, by Figure 3, 2750 million cu. ft. per tide which is 23 per cent of the tidal flow.

TABLE III

RELATIONSHIP BETWEEN LAND WATER RUN-OFF AND NEW SEA WATER ENTERING AT THE NARROWS

Land Water Run-Off at the Narrows (C. F. S.)	New Sea Water Passing the Narrows (Mil. Cu. Ft. per Day)	Dissolved Oxygen in New Sea Water (Mil. Pounds per Day)*
5,000	687	0.309
10,000	1795	0.808
15,000	2520	1.135
20,000	2910	1.310
30,000	3040	1.368
40,000	2700	1.215
50,000	2420	1.090
60,000	2190	0.985
80,000	1930	0.869

* Assuming saturation at 70° F.

From a study of tidal circulation and displacement Black and Phelps computed this value at 19 per cent. While the two values substantially agree there is a fundamental distinction. The Black and Phelps formula yields a uniform trend line for the depletion of the oxygen in the Harbor, progressing with population growth but uninfluenced by considerations of run-off or tidal variation. The present formula is based primarily upon the run-off of the Hudson River and, as will be indicated in a later section,

fixes a value for the annual conditions which is irregular in its aspects, fluctuating by relatively large amounts above and below the mean trend line.

Mean tidal conditions have been taken in the determination of the amount of sea water entering the Harbor each day. This treatment is not entirely sufficient even when dealing with mean monthly or even seasonal conditions. There are certain long-period elements of the tidal phenomena related to the precession of the moon's nodes (18.5 years) and the rotation of the line of apsides (9 years), which make for higher or lower mean annual tides on any given year. Moreover, the volume of the tidal flow on any one day is largely influenced by the relation of that day to certain lunar cycles. The chief short-period elements affecting this volume are the age of the moon reckoned from new moon, giving a monthly 28-day period and 2 unequal 14-day periods; the time of the new-moon tide since last perigee and variations in the eccentricity of the moon's orbit. The distance of the earth from the sun, reckoned from perihelion, gives an annual cycle which does not influence the summer data. None of these factors has been given any detailed consideration in the present computations.

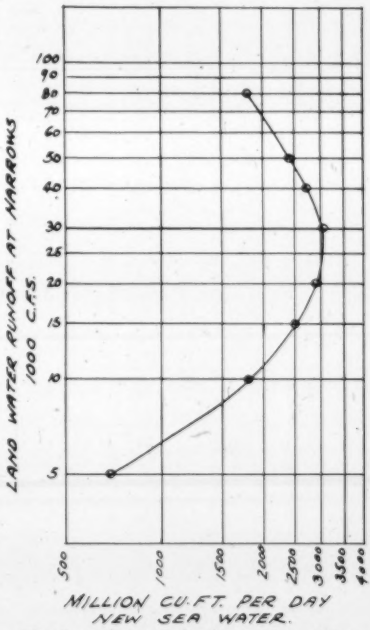


FIG. 3.—Relationship Between Land Water Run-Off and New Sea Water Entering Upper Bay at Narrows.

As an indication of the importance of the long-period tidal variations, however, it may be noted that the principal lunar components of the tide at New York are affected by a periodic variation of approximately 7.4 per cent of the mean height over a period of 18.5 years. If it be recalled that only about 20 per cent of the tidal flow is new sea water and that a

variation of 7.4 per cent may be regarded as occurring in that last 20 per cent, the actual variation in the amount of new sea water entering the Harbor may be as high as one-third the mean value.

In any detailed analysis of the observed conditions in past years the actual tidal volume should be determined for the period covered by the

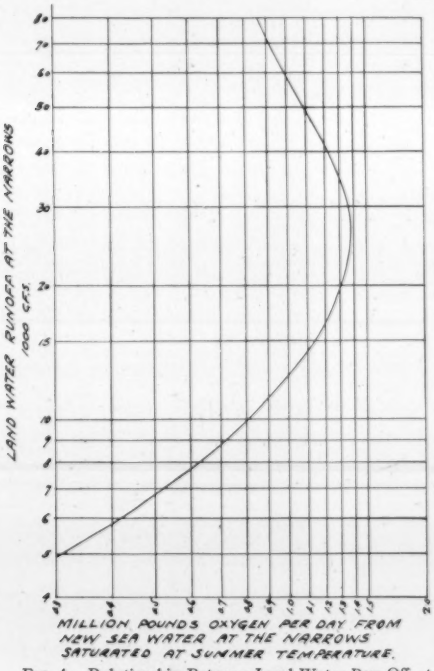

LAND WATER RUNOFF AT THE NARROWS
1000 CFS.
MILLION POUNDS OXYGEN PER DAY FROM
NEW SEA WATER AT THE NARROWS
SATURATED AT SUMMER TEMPERATURE.

FIG. 4.—Relationship Between Land Water Run-Off at the Narrows and Pounds Oxygen per Day from New Sea Water Saturated at Summer Temperature.

observations. This may be done with sufficient accuracy by reference to the published tide tables. For predictions of future conditions, the tidal height for any year may be determined by the general formulas prepared by the United States Coast and Geodetic Survey.

For the purpose of the further computations the volumetric data of

Figure 3 are transformed into D. O. values, Figure 4, assuming the new sea water to be oxygen saturated. These values will later be modified appropriately to fit the actual conditions.

A further source of D. O. in the Harbor is found in the excess southward flow of waters through the East River from Long Island Sound. The mean discharge of the East River, considered as a continuously flowing stream, has been taken, upon the report of Professor Henry Mitchel of the United States Coast and Geodetic Survey, at 10,000 cu. ft. per second. This actually constitutes a portion of the so-called new sea water entering the Bay with each flood tide. However, because of its point of origin and course of flow it must be dealt with separately. Since this phenomenon is likewise dependent upon tidal movement it must in a complete analysis be dealt with as a variable, affected in the same way as the tidal flow through the Narrows. Being merely an interference phenomenon between two tidal movements it probably varies in about the same periods but the extent and direction of the variations cannot be assumed to be even similar.

Pollution of New York Harbor

The actual distribution of the existing pollution of the Harbor at any time is determined in part by the location of sewer outlets and the distribution of the contributing pollution. It is quite necessary, therefore, to establish this population distribution as a basis for the further computations. This has been done for each of the decade years 1910, 1920 and 1930 by compiling census populations by natural drainage areas tributary to certain assumed points of outlet, conveniently and fairly evenly spaced. The results are shown on the map, Figure 5. In the Hudson River, each of these points of outlet has then been considered as discharging into a river having a continuous net southward velocity determined solely upon the basis of the river run-off and its cross-sectional area, taken at 146,000 sq. ft.

This value of the net southward velocity of the river water differs materially from values adopted by the Metropolitan Sewerage Commission as the result of float tests and also from values computed from the charts of the United States Coast and Geodetic Survey employed in determining net velocities between Albany and New York. It is necessary, therefore, to give some consideration to the reasons for the discrepancy and to the further reasoning which has led to the selection of the values which we have adopted.

In the region where a salinity gradient is encountered, we may picture a salt water river running up-stream discharging into the downward flow at such intervals and in sufficient quantities to provide the observed salinity gradient. With constant cross-sectional area this would lead to

a continuously increasing net velocity on the part of the downward flowing section due to the increasing volume of that section and to the increasing portion of the total section required for the up-flowing stream.

The actual situation is the hydraulic equivalent of this imaginary one except that there is no sharp line of demarcation between the up-flowing and the down-flowing streams or between sea and land water. The salinity is only slightly higher at the bottom and what actually happens is a northward movement of this slightly more saline water in excess of its southward movement and a compensating excess southward flow of the lighter surface waters. It is this surface velocity which is actually measured by

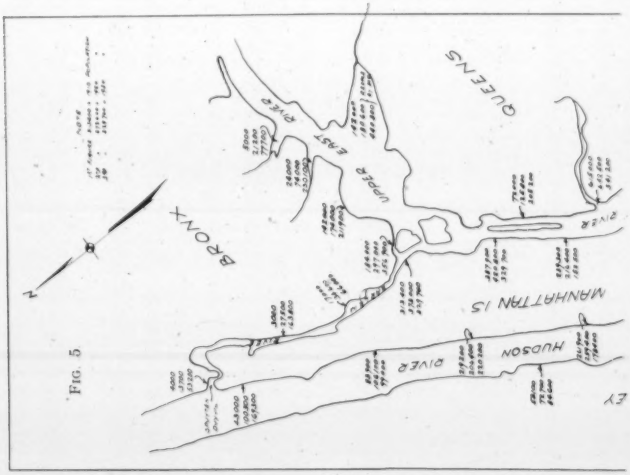
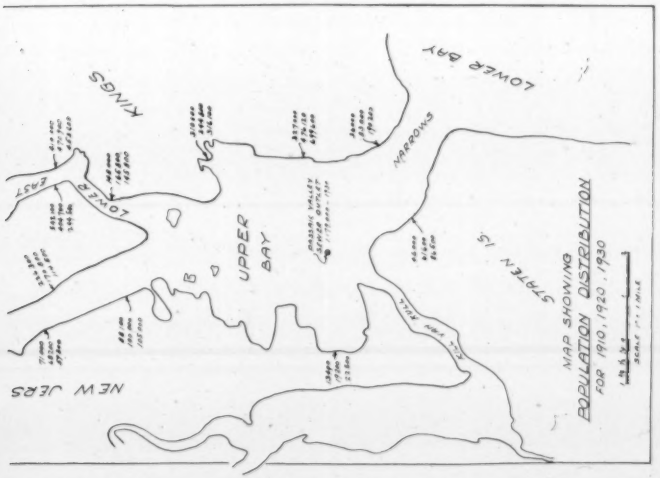


FIG. 5

floats and current meters. But since the up-flowing stream at any cross-section contains its full quota of pollution, it is the net southward velocity of these two streams which determines the mean life of the sewage in the river. Under any assumption of the distribution of land and sea water in these two hypothetical streams, this net southward velocity is essentially equal to that obtained by dividing the land water run-off by the cross-sectional area, the only error being that due to the fact that the upward flowing stream is slightly more saline than the downward flowing. For the determination of the total effect of all pollution, measured at the Narrows, velocities and corresponding times of passage based upon the net land water run-off have therefore been adopted as best representing the

actual conditions with which we have to deal. For the East River a similar theoretical southward velocity based upon the net southward flow over a tidal period, yielding a continuous flow of 10,000 c. f. s., has been used. The Harlem River drainage has been arbitrarily distributed according to its tidal currents, whereby a part of the pollution enters the East River at Hell Gate and a part the Hudson at Spuyten Duyvil. While this treatment of the complicated tidal action seems to be rational for the Upper Hudson where the points of pollution are widely distributed and for the Narrows where the pollution is entirely from above, and while it determines results which are reasonably in agreement



with the actual results of the analyses when applied to the conditions at the Narrows, it is not applicable to those sections of the river or bay which are affected by the upward tidal flow of pollution from sources further down-stream. It will be shown later how it has been necessary to deal with the tidal phenomena in the analysis of conditions in the various subdivisions of the Harbor and River.

With the distributed populations on the three decade years and with the stream velocities derived as outlined above, we have computed the time of passage from each point of discharge to the next lower one, reduced the corresponding tributary population by the known rate of reduction of B. O. D., added the next population, again reduced this total

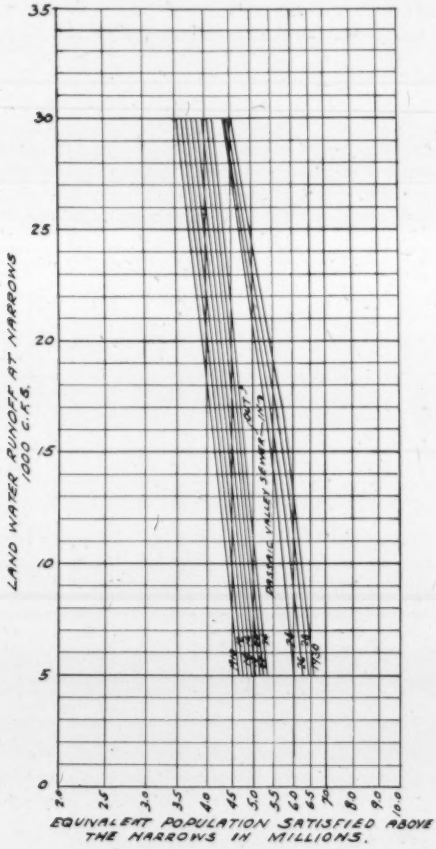


FIG. 6.—Relationship Between Equivalent Population Satisfied Above the Narrows and the Land Water Run-Off for the Period 1910-30.

to the next point and so on down to the mouths of the rivers. Summing the individual reduction items we obtain the total rate of satisfaction of

B. O. D. through the course of the rivers while the last term gives the total demand contributed by the rivers to the Upper Bay.

In the Bay itself a similar displacement equation has been employed to obtain the mean time of detention. Here again, although the problem is somewhat more complex, there are alternative concepts. Assuming a complete mixing of each addition of new sea water, there would be a removal of about 20 per cent of the existing pollution on each tide, leaving about 1 per cent at the end of 5 days. This takes no cognizance of the Hudson River run-off. The displacement theory gives approximately

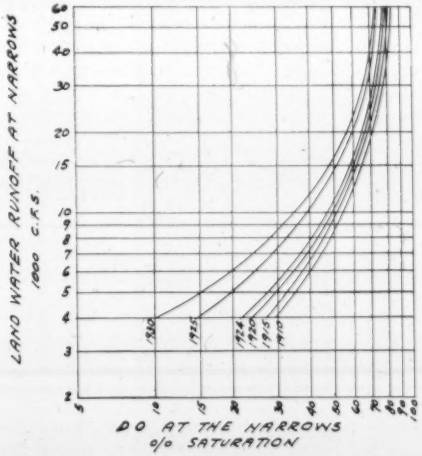


FIG. 7.—Relationship Between Dissolved Oxygen at the Narrows and the Land Water Run-Off for the Period 1910–30.

5 days as the time of passage through the Bay under mean summer flows of the Hudson River. While 5 days is sufficient in either case to carry pollution through the Bay to the sea, the difference in the two results arises from the fact that 5 days of continuous passage through the Bay results in an oxidation of 68 per cent of the B. O. D., while the intermittent discharge of 20 per cent per tide results in a corresponding oxidation of but 25 per cent of the total. Since the pollution reaching the Upper Bay has, for the most part, already been partially oxidized during its passage through the rivers, this difference is not so great as might appear, so that under the population conditions of 1910, the theory of complete mixing

TABLE IV

EQUIVALENT POPULATION DEMAND IN HUDSON RIVER TO BATTERY, 1910

	Station	Miles from Station 1	Time of Passage from Station 1 in Days 96%*	50%*	20%*	5%*	Pop. Added	Equivalent Population (Thousands) 96% a*	b*	50% a	b	20% a	b	5% a	b
1.	Spuyten Duyvil	0.0	0.0	0.0	0.0	0.0	56		56		56		56		56
2.	Dyckman Street	0.8	0.23	0.35	0.45	0.6	43	54	97	52	95	50	93	49	92
3.	142nd Street	4.0	1.2	1.9	2.4	3.2	84	77	161	65	149	60	144	51	135
4.	96th Street	6.2	1.9	3.0	3.8	5.0	219	120	339	114	333	102	321	90	309
5.	West N. Y., N. J.	8.0	2.5	3.8	4.8	6.3	53	290	343	280	333	255	308	230	283
6.	46th Street	9.0	2.8	4.3	5.4	7.1	262	315	577	290	552	270	532	240	502
7.	Hoboken	10.8	3.4	5.1	6.5	8.5	71	510	581	460	531	332	403	365	436
8.	Charles Street	11.3	3.5	5.4	6.8	9.0	226	570	796	500	726	385	611	380	606
9.	Jersey City	13.0	4.1	6.2	7.8	10.3	88	690	778	600	688	480	568	450	538
10.	Battery	13.8	4.2	6.3	8.3	11.0		720	720	660	660	510	510	460	460
						Total	1102								
						Satisfied			382		442		592		642

* NOTE: The 96% flow is 25,000 c. f. s.; 50%, 16,100; 20%, 12,800; and 5%, 9700.
Column (*a*) equivalent population remaining at station from station above.
Column (*b*) total equivalent population at station.

in the Bay, employed by Black and Phelps, gave D. O. values in satisfactory agreement with the facts. With increasing population, however, and especially in the last decade, it has become increasingly evident that the D. O. in the Harbor is decreasing faster than the population increase. In short a discrepancy which was too slight to notice under a general condition of 75 per cent saturation of D. O. has become marked when the D. O. values have reached 50 per cent.

Table IV illustrates the method of procedure in computing the actual consumption of oxygen in the various sections of the system under the conditions of 1910. Table V gives similar data for the East River under a uniform flow of 10,000 c. f. s., and finally Table VI carries the combined rivers to the Narrows. These are all for the 1910 population. Similar computations have been made for the years 1920 and 1930. Figure 6 gives the summary of a series of computations similar to the above for the two rivers and then for the Upper Bay carrying the final results to the Narrows. It gives, therefore, the total population demand which is satisfied in the Harbor computed at four values of the Hudson River run-off and at three decade years, and interpolated for each two years between the decade years and continuously through the run-off values. These values will be made the basis of a comparison of the demand satisfied in the Harbor and the Harbor resources in the form of D. O., the balance between which determines the final condition of the Harbor waters.

TABLE V

EQUIVALENT POPULATION DEMAND IN EAST RIVER TO BATTERY, 1910

	Station	Miles from Station 1	Time of Passage from Station 1 in Days	Equivalent Pop. (Thousands) Added	Remaining from Above	Total
1.	Flushing Bay	0	0	147		147
2.	Bronx River	1.2	2.0	24	92	116
3.	Rickers Is.	3.0	5.0	142	58	200
4.	Harlem River	4.0	6.6	515	138	653
5.	North End Blackwells Is.	6.2	7.6	388	521	909
6.	Middle Blackwells Is.	7.0	8.0	72	810	882
7.	South End Blackwells Is.	8.0	8.5	239	790	1029
8.	Newtown Cr.	9.2	9.0	615	900	1515
9.	U. S. Navy Yard	11.0	9.8	952	1260	2212
10.	Brooklyn Bridge	12.6	10.5	148	1900	2048
11.	Battery	13.6	12.0		1460	1460
			Total	3242		
			Remaining	1460		
			Satisfied	1782		

The Dissolved Oxygen in the Harbor

The D. O. of the Harbor water represents the difference between the oxygen available and the oxygen utilized in satisfying the demands of

TABLE VI

EQUIVALENT POPULATION DEMAND IN UPPER BAY TO NARROWS, 1910

	Station	Miles from Station 1	Time of Passage from Station 1 in Days 96%	50%	20%	5%**	Pop. Added at Station in Thousands	Equivalent Population (Thousands) 96% a**	96% b**	50% a	50% b	20% a	20% b	5% a	5% b
1.	Battery	0	0	0	0	0		2180*	2180	2120	2120	1970	1970	1920	1920
2.	Gowanus Bay	2.2	1.3	1.7	1.9	2.2	310	1610	1920	1440	1750	1290	1600	1130	1440
3.	Bayonne	3.0	1.7	2.2	2.6	3.0	13	1750	1763	1550	1563	1350	1363	1200	1213
4.	Robbins Reef	3.5	2.0	2.6	3.0	3.5	0								
5.	63rd Street	4.0	2.3	3.0	3.4	4.0	327	1550	1877	1300	1627	1150	1477	960	1287
6.	80th Street	5.0	2.9	3.7	4.3	5.0	82	1640	1722	1330	1412	1180	1262	1020	1102
7.	Narrows	7.0	4.0	5.2	6.0	7.0		1350	1350	1000	1000	862	862	685	685
		Added below Battery					732								
		Added above Battery							2180		2120		1970		1920
		Total added							2912		2852		2702		2652
		Remaining							1350		1000		862		685
		Satisfied							1562		1852		1840		1967

* Remaining population equivalent from East River and Hudson River.

** See note, Table V.

pollution. The rate at which this demand is satisfied having now been determined, it is next necessary to turn to the available oxygen resources. These are derived from three principal sources: the land water run-off of the Hudson River, the new sea water entering the Bay and re-aeration from the atmosphere. The Hudson River is the predominant factor influencing the D. O. resources. Re-aeration is of minor importance while the new sea water entering at the Narrows and the oxygen contributed by the Upper River are both controlled by the land water run-off, which likewise determines the life of the sewage in the Harbor.

The influence of all the pollution entering the Harbor is felt at the Narrows. The D. O. at the Narrows has been computed for the years 1910, 1915, 1920, 1924, 1925, 1930, each year under five conditions of land water run-off, 5000, 7000, 12,000, 17,150 and 25,000 c. f. s. flow. The final results are summarized in Table VII and Figure 7 from which values for intermediate years may be interpolated. It will be noted, particularly in the graph, how much more sensitive the system has become in recent years to fluctuations in river run-off, a condition of apparent instability previously pointed out as characterizing the actual analytical results from year to year.

TABLE VII

DISSOLVED OXYGEN CONTENT OF THE HARBOR WATER AT THE NARROWS AS COMPUTED FOR CERTAIN YEARS AND AT CERTAIN RATES OF FLOW OF THE HUDSON RIVER

(Per Cent of Saturation)

	Hudson River Run-Off				
Year	25,000 C. F. S	17,150 C. F. S.	12,000 C. F. S.	7,000 C. F. S.	5,000 C. F. S.
1910	74.3	67.7	59.1	44.5	35.5
1915	72.4	66.0	56.8	41.1	33.0
1920	70.7	63.8	54.8	39.1	29.5
1924	69.3	61.9	52.5	37.0	27.8
1925	65.0	55.1	44.2	28.6	19.6
1930	62.8	52.1	40.8	24.0	15.2

The details of the computation of Table VII are illustrated in Table VIII. This table refers to a land water flow of 17,150 c. f. s., the mean summer run-off at the Narrows.

Column 2 is the population equivalent of the pollution satisfied in the Harbor above the Narrows obtained from Figure 6. Column 3 represents the daily oxygen equivalent of this population. Column 4 gives the D. O. of the new sea water entering the Harbor at the Narrows in per cent of saturation. This is derived as follows. The up-stream flow of sea water is opposed to the outward flow of the pollution and, hence, its D. O. value at any point has been reduced by its passage through pollution further down-stream. In Table IX is shown the equivalent population satisfied below the Narrows and hence the loss of oxygen suffered by the incoming

TABLE VIII

DETAILS OF COMPUTATION OF DISSOLVED OXYGEN

(Specimen—Stream Flow, 17,500 C. F. S.)

Year	Demand Satisfied Above Narrows		Oxygen from New Sea Water at Narrows		Oxygen from Hudson		Oxygen from (Mil. Lbs. per Day)			Oxygen Remaining	
	Pop. (Mil.)	Oxygen (Mil. Lbs)	% Sat.	Mil. Lbs. Day	% Sat.	Mil. Lbs. Day	East R.	Re-aeration	Tot.	Mil. Lbs. Day	% Sat.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1910	4.08	0.900	91.8	1.120	98.2	0.770	0.389	0.240	2.519	1.619	67.7
1915	4.30	0.946	90.8	1.108	98.0	0.768	0.389	0.255	2.520	1.574	66.0
1920	4.54	1.000	90.0	1.098	97.8	0.767	0.389	0.270	2.524	1.524	63.8
1924	4.72	1.040	89.2	1.088	97.2	0.763	0.389	0.280	2.520	1.480	61.9
1925	5.38	1.185	84.1	1.025	97.2	0.763	0.389	0.325	2.502	1.317	55.1
1930	5.73	1.260	82.8	1.010	96.5	0.757	0.389	0.350	2.506	1.246	52.1

Hudson River, 100 per cent saturation = 0.782
East River, 100 per cent saturation = 0.389
New Sea Narrows, 100 per cent saturation = 1.220

2.391 Mil. lbs. per day at 100%

sea water from the source of oxygen-saturated sea water, which has been arbitrarily located at the previously described 90 per cent salinity datum. The demand curve has been extended to this point and the corresponding reduction in population equivalent recorded. The values for any year appear to be nearly constant for flows ranging from 4000 c. f. s. to 25,000 c. f. s., the extra time and distance to the datum point with lower flows just compensating the decreased concentration of residual demand. With these data, the actual D. O. values of the new sea water entering at the Narrows are determined for a range of land water flows as shown in Table X and plotted in Figure 8.

TABLE IX

EQUIVALENT POPULATION SATISFIED DURING THE PASSAGE FROM THE NARROWS TO THE SOURCE OF 100% SATURATED SEA WATER

Year	Equivalent Population Satisfied Narrows to 100% Sat. Sea Water (Thousands)	Oxygen Used in the Stretch (Mil. Lbs. per Day)
1910	467	0.103
1920	554	0.122
1924	600	0.132
1925	885	0.195
1930	955	0.210

TABLE X

RELATIONSHIP BETWEEN LAND WATER RUN-OFF AND DISSOLVED OXYGEN IN NEW SEA WATER AT THE NARROWS

Run-Off, C. F. S.	At Saturation	Dissolved Oxygen in the New Sea Water: Million Pounds per Day Utilized by Demand Below Narrows					Per Cent Saturation Remaining at Narrows				
		1910	1920	1924	1925	1930	1910	1920	1924	1925	1930
5,000	0.31	0.103	0.122	0.132	0.195	0.210	67	61	51	37	32
10,000	0.80	0.103	0.122	0.132	0.195	0.210	87	85	83	75	74
15,000	1.13	0.103	0.122	0.132	0.195	0.210	91	89	88	83	81
20,000	1.32	0.103	0.122	0.132	0.195	0.210	92	91	90	85	84
25,000	1.37	0.103	0.122	0.132	0.195	0.210	93	91	90	86	85

Returning to Table VIII, Column 5 is obtained by applying the percentage saturation values of Column 4 to the saturation values obtained from Figure 8. In Column 6 the D. O. of Hudson River run-off is based on the data for the upper section of the Hudson River for 1930, previously shown to be 96.5 per cent at Spuyten Duyvil. The deficit for each other year is taken proportional to the up-river population of that year. Column 7 is obtained by applying the values of Column 6 to the amount of oxygen carried in the Hudson River run-off at 100 per cent saturation. Column 8 is the amount of oxygen per day available from the resultant sea water flow of the East River, at full saturation.

Column 9 shows the amount of oxygen available from re-aeration. The rates of re-aeration are based upon data presented by Black and Phelps for fresh water at 20° C., with excessive allowances for mixing, and are

deemed liberal. The daily absorption of oxygen over the entire Harbor under three conditions of saturation deficits and based upon the value at the Narrows as the control is shown in Table XI and plotted in Figure 9. The tabulated values in Table VIII are taken from Figure 9 by a series of successive approximations.

Column 10 of Table VIII gives the total of oxygen available from all sources, being the sum of Columns 5, 7, 8 and 9. Column 11, the difference

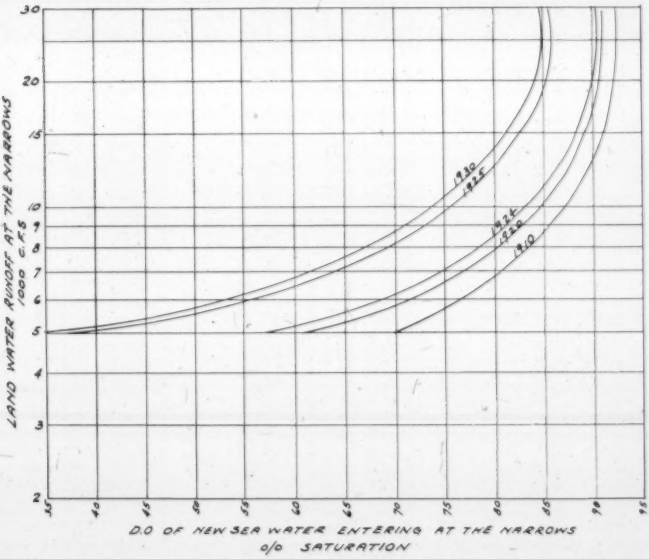


FIG. 8.—Relationship Between the Dissolved Oxygen of the New Sea Water Entering at the Narrows and Land Water Run-Off for Period 1910–30.

between 10 and 3, represents the difference between the amount of oxygen available and the amount utilized each day. Column 12, the D. O. at the Narrows, is the ratio of the amount of oxygen remaining to the amount of oxygen the waters would contain at saturation, expressed as per cent saturation. The values at the other four basic flows shown in Table VII are computed similarly.

A comparison of the computed oxygen values at the Narrows with the values reported by the New York City Board of Estimate and Apportion-

TABLE XI

RELATION BETWEEN THE DISSOLVED OXYGEN VALUE AT THE NARROWS AND THE OXYGEN ABSORBED BY RE-AERATION OVER THE ENTIRE HARBOR

D. O. at the Narrows (% Saturation)	Re-aeration Over Entire Harbor (Mil. Lbs. per Day)
70	0.225
50	0.362
30	0.615

ment as averages, June 1 to October 1, for the years 1909–1931 and similar averages reported by the Passaic Valley Sewerage Commission 1923–1930, is shown in Table XII and Figure 10. For the twenty-two year period the probable error of an individual annual value is 11.6 per cent of the observed value.

TABLE XII

COMPARISON OF DISSOLVED OXYGEN AT NARROWS AS COMPUTED BY FORMULA AND AS DETERMINED BY ANALYSIS, 1909–31

	D. O. at Narrows, Average, June 1 to October 1 (Per Cent Saturation)		
Year	Computed Values	Determinations by N. Y. C. Board Est. & App.	Determinations by Passaic Valley Sewage Commission
1909	71	83	
1910	68		
1911	64	76	
1912	64	70	
1913	51	69	
1914	63	68	
1915	68	78	
1916	69	64	
1917	72	64	
1918	60	61	
1919	64	58	
1920	57	52	
1921	50	36	
1922	70	60	
1923	59	58	52
1924	66	72	68
1925	57	56	69
1926	55	41	52
1927	48	48	57
1928	61	45	56
1929	56	52	54
1930	41	51	55
1931	52	48	

Figure 11 illustrates the monthly variation in D. O. as computed at the Narrows. The values for June, July, August and September are computed for each year based on the run-off of May, June, July and August, respec-

tively, since, as previously shown, a summer flow condition measured near Troy is reflected in the flow at the Narrows, approximately one month later. It is apparent that the expected monthly variations throughout the summer are much greater than the recorded annual variations and that the observed values reported as averages for the period June 1 to October 1 may deviate considerably from the true average, unless the samples taken are evenly distributed throughout the period.

In view of the errors inherent in sampling, both as to location of sampling

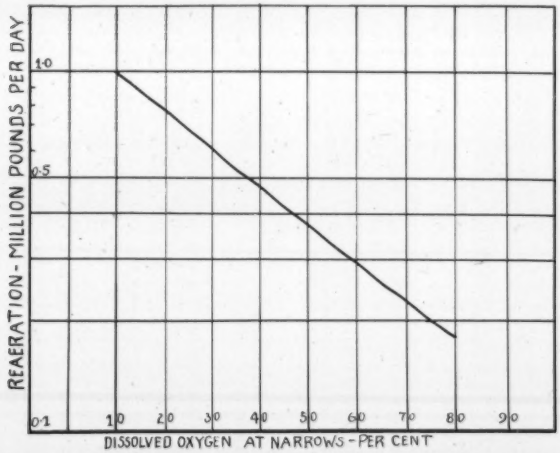


FIG. 9.—Relation Between the Amount of Oxygen Absorbed by Re-aeration Over the Entire Harbor and the Dissolved Oxygen Value at the Narrows. (Based Upon the Oxygen Gradient Studies of This Paper and Upon the Formula of Black and Phelps.)

points and particularly as to balancing the tidal and seasonal fluctuations and likewise in view of the errors of measurement of stream-flow and other physical characteristics used in the computations, the results obtained above indicate that the fundamental treatment presented here is basically sound and probably capable of yielding data quite as reliable as those obtained by actual analysis.

The Subdivisions of the Harbor

Conditions at the Narrows reflect the total result of the pollution contributed to these waters. The distribution of pollution, however, is not

proportioned to the relative capacities of the various subdivisions of the Harbor to receive and oxidize sewage so that there results a very unequal distribution of the effects of pollution in these sections. For some years past the lower East River has been near the point of total oxygen depletion over a considerable portion of the summer and on frequent occasions complete depletion has occurred at certain points. These facts are recognized in the location of the first major treatment plant for the city of New York which has been placed at Wards Island where it will relieve the load upon the East River.

Owing to tidal circulation the condition of the lower Hudson is largely influenced by the condition of the East River, and *vice versa*, so that im-

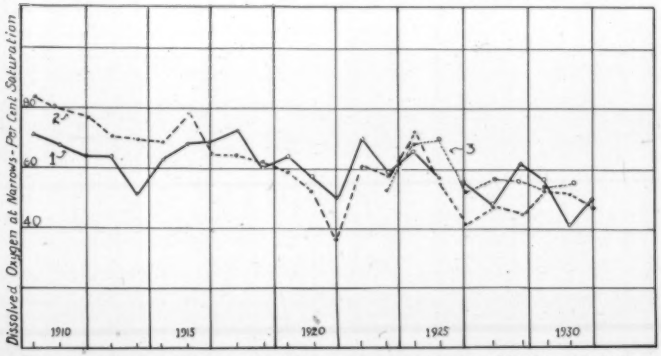


FIG. 10.—Dissolved Oxygen at the Narrows, June 1 to Oct. 1, 1909–31. (1) As Computed. (2) As Reported by Board of Estimate, New York. (3) As Reported by Passaic Valley Sewage Commission.

provement brought about by the Wards Island plant will be felt throughout the system. Thus any proper approach to the problem of designing and particularly of locating sewage treatment works must take note of the ultimate distribution of the sewage of the city throughout the various subdivisions of the Harbor.

The D. O. values throughout the Harbor follow steep gradients. Above New York City the values are relatively high, running down more or less uniformly to a minimum point located somewhere between the Battery and 96th Street, depending upon the tide and run-off. From this minimum point the values again increase rather uniformly through the Upper Bay to the Narrows. In a fresh water river, the building up of the D. O. gradient is largely brought about by re-aeration. In New York Harbor,

re-aeration is a minor though quite appreciable factor, and the new sea water entering at the Narrows is chiefly responsible for the marked rise in the lower section of the gradient.

Picturing the Harbor as the resultant of a land-water flow toward the sea and a sea-water flow up-stream, the D. O. at any point along the gradient for the mean tidal condition can be computed as a resultant of the land water run-off and pollutional demand satisfied above the station, the sea-water inflow and demand satisfied below the station, and re-aeration This computation is outlined in Table XIII for a mean summer run-off and under 1930 populations. The following data are employed in preparing this table.

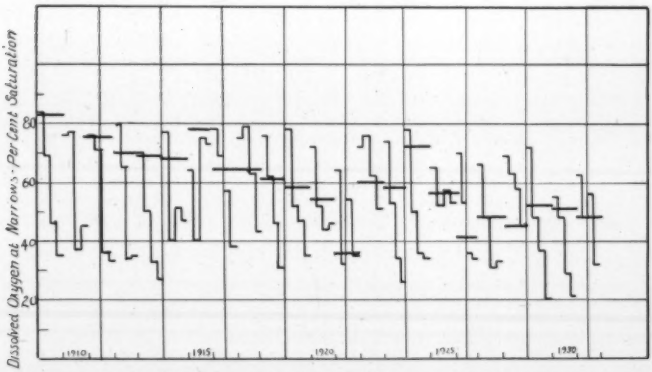


FIG. 11.—Dissolved Oxygen at the Narrows, 1909–31. (a) As Computed for Each Month, June to Sept. (Indicated by the Step-Like Figure for Each Year.) (b) As Reported for the Summer by the Board of Estimate (Solid Dash).

The equivalent population satisfied above any particular station, neglecting the influence of oscillating tides, is obtained from an integration of the demand satisfied for a time of passage based on a uniform resultant seaward flow. Figure 12 and Table XIV show the summation of the equivalent population satisfied above any station on the East River, the Hudson River, of the Upper Bay.

It is necessary, however, to take into account the tidal oscillations in order to obtain the actual demand satisfied especially for the lower eight miles of both the Hudson and the East River. On the ebb tide the entire contents of the Hudson up to 96th Street and the entire contents of the East River up to Hell Gate are combined in the Upper Bay and mixed

TABLE XIII

DISSOLVED OXYGEN GRADIENT THROUGH UPPER BAY AND HUDSON RIVER, COMPUTED FOR 1930 POPULATION DISTRIBUTION AND MEAN SUMMER RUN-OFF

Station Miles Above Narrows	Eq. Population Satisfied Above the Station Millions	Utilized Above*	Oxygen (Million Pounds per Day) From Sea Water At 100%**	From Sea Water Available†	East River 100%	Hudson River 96%	Re-aeration	Total	Balance	D. O. % Sat.
0	5.85	1.286	1.220	1.012	0.389	0.755	0.350	2.506	1.220	51.0
4	4.55	1.000	1.015	0.523	0.389	0.755	0.320	1.987	0.987	45.2
9	1.32	0.291	0.775	0.015	...	0.755	0.122	0.892	0.601	38.6
12	0.80	0.176	0.630	0.000	...	0.755	0.080	0.835	0.659	46.6
15 (96th St.)	0.49	0.108	0.510	0.000	...	0.755	0.044	0.799	0.691	53.5
21.8 (Spuyten Duyvil)	0.17	0.037	0.300	0.000	...	0.755	0.020	0.775	0.738	67.0
25.0 (Yonkers)	0.02	0.004	0.240	0.000	...	0.755	...	0.755	0.751	73.5

* From Table XIV.

** From Table XV.

† Previous column times per cent saturation from Table XVII.

laterally, so that on the flood tide the combined demand is returned in proportion to the tidal flow, about forty per cent going back to the East River and about sixty per cent to the Hudson River. The proportion of each river's demand that is thus mixed can be estimated from the length of time the demand from a particular station of one river is comingled with that of the other river in the Upper Bay. The demands down to the mouths of the rivers are in the Upper Bay for a complete ebb period

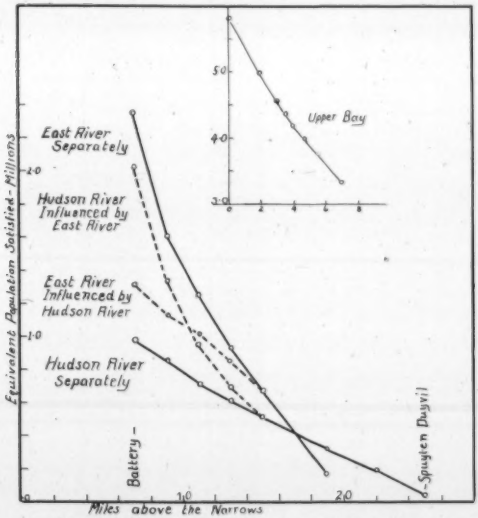


FIG. 12.—Population Equivalent to the B. O. D. Satisfied Above Certain Points, Spuyten Duyvil to Narrows, Mean Summer Run-Off of Hudson and Population Distribution of 1930.

and hence are completely mixed. The demands two miles above the mouths are considered three-quarters mixed and one-quarter unmixed, four miles above, one-half mixed and one-half unmixed, six miles above, one-quarter mixed and three-quarters unmixed, while at eight miles above, the two rivers are considered independent of influence from each other. Through the Bay the two rivers are combined into one demand.

The sea water flowing up-stream past any particular station is governed by the factors previously discussed in the calculations for the new sea water

TABLE XIV

EQUIVALENT POPULATION SATISFIED UNDER 1930 POPULATION DISTRIBUTION AND MEAN SUMMER RUN-OFF

Station Miles Above Narrows	Equivalent Population Satisfied (Thousands) Hudson River Separate	East River Separate	Hudson River Plus Influence of East River	East River Plus Influence of Hudson River	Upper Bay
25	20		20		
22	170		170		
19	300	150	300	150	
15	490	660	490	660	
13	600	920	680	839	
11	700	1240	940	1000	
9	840	1600	1323	1117	
7	970	2350	2020	1300	3320
5					4050
3					4550
2					5100
0					5850

entering at the Narrows, namely, the volume of the tidal flow, the per cent of land water in the tidal flow and the land water run-off. Table XV gives the computed amounts of sea water flowing by any station along the brackish water section. The amount of oxygen available at any particular station from this sea water is dependent upon the amount of pollution the sea water flows through before it reaches the station. The D. O. of the sea water computed for each mile interval above the Narrows, as outlined in Table XVI, is shown in Figure 13.

TABLE XV

SEA WATER FLOW UP THE HUDSON RIVER TO MAINTAIN THE SALINITY GRADIENT THROUGHOUT THE BRACKISH WATERS. MEAN SUMMER RUN-OFF

Location	% Land Water in Ebb Flow	Million Cu. Ft. New Sea Water Flowing per Tide	Uniform Rate of Sea Water Flow Up-Stream C. F. S.	Million Lbs. Oxygen per Day from New Sea Water at 100% Saturation
Battery				
Mouth of Hudson River	42.0	1000	22,300	0.865
2 Mi. above Battery	44.6	895	20,000	0.778
4 Mi. above Battery	48.2	776	17,300	0.674
96th Street	54.2	610	13,600	0.528
11 Mi. above Battery	60.5	473	10,600	0.411
Spuyten Duyvil	67.0	356	7,940	0.308
21 Mi. above Battery	77.6	209	4,650	0.181
27 Mi. above Battery	88.0	99	2,220	0.086
Narrows	29.0	1410	31,100	1.22

These quantities are all employed in the computation shown in Table XIII. They are based upon uniform flow of land and sea water and therefore the D. O. data of the last column represent the mean tidal condition.

TABLE XVI

PER CENT SATURATION SEA WATER FLOW UNDER 1930 DEMAND AND MEAN SUMMER RUN-OFF

Station Distance Above Narrows Miles (1)	Population Satisfied in the Stretch (2)	Million Lbs. Oxygen per Day Consumed by Pop. of Col. 2 × 0.22 (3)	Million Lbs. Oxygen per Day from Sea Water at 100% Sat. (Summer Temp.) (4)	Amount of Oxygen (Million Lbs. per Day) Sea Water Flowing Past This Station Contained at Preceding Station (5)	Amount Oxygen, (Millions Lbs. per Day) Sea Water Contained When It Reached the Station (6)	% Sat. of Sea Water Flow Available at the Station (7)
0 Narrows						83.0*
1	750	0.165	1.117	0.927	0.762	68.2
2	300	0.066	1.112	0.763	0.697	62.2
3	250	0.055	1.065	0.662	0.607	57.0
4	250	0.055	1.015	0.578	0.523	51.5
5	250	0.055	0.965	0.497	0.442	45.8
6	350	0.077	0.915	0.419	0.342	37.4
7	330	0.073	0.870	0.325	0.252	29.0
8	370	0.082	0.820	0.182	0.100	12.2
9	360	0.079	0.775	0.095	0.015	2.0

* Taken from Fig. 9.

They are indicated in Figure 14 "mean tide." If the influence upon the oxygen demand of the six-hour difference in time between flood and ebb be neglected, the condition existing at the end of the flood will be practically represented by shifting the D. O. gradient up-stream four miles. Likewise, the condition at the end of the ebb is procured by shifting the gradient four miles down-stream. These are likewise indicated in Figure 14.

The movement of the sea water up-stream is, in reality, a complicated process of exchange between land and sea-water mixtures. The net

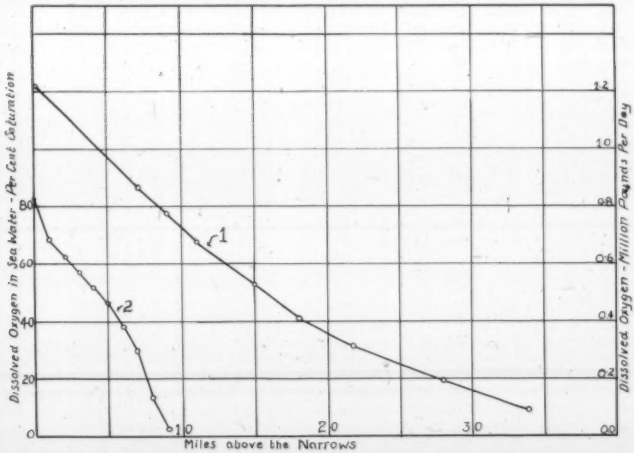


FIG. 13.—Dissolved Oxygen Available from Sea Water Under Mean Summer Run-Off of Hudson River of 1.2 c. f. s. per Sq. Mile. Curve 1; Million Pounds per Day Under Conditions of Saturation at All Points. Curve 2; Residual Under Conditions of 1930 Population Demand, per Cent of Saturation

effect is obtained, at any particular station, from the simplified concept here employed, the details of which are apparent from Table XIII. There are three major elements affecting it under a given population distribution, namely, the land water run-off which exerts the same effect as in any fresh water river; the oscillatory movements of the tides; and the up-stream flow of sea water. This last named factor controls the oxygen gradient as it slopes upward through the Bay toward the Narrows while the river run-off controls the gradient sloping downward from the upper river to a minimum point. The effect of the pollution from any point

upon a section up-stream is more far-reaching than the eight mile oscillatory tidal movement. It extends, in reality, to the cross-section, beyond which there is no exchange of sea water, *i. e.*, the end of the brackish waters. The decrease in the D. O. values for any section, below the values which would be obtained under normal fresh-water river conditions, is a measure of the amount of pollution carried up-stream.

This computation has been made only for one set of conditions corresponding to the 1930 population and mean summer run-off, 1.2 c. f. s. per sq. mile. For comparison, 1929 and 1930 analytical data are shown, the stream flow having been 0.7 for June, July and August of each year.

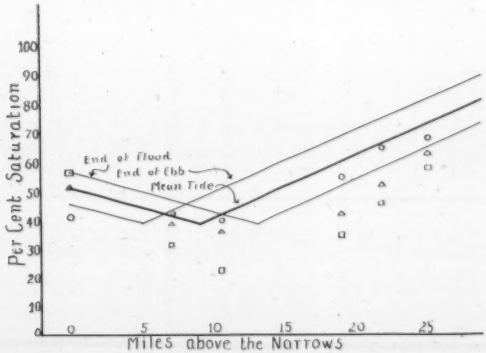


FIG. 14.—Dissolved Oxygen Gradients—Computed, 1930 Population Conditions and Mean Summer Run-Off 1.2 c. f. s. per Sq. Mile. Mean Analytical Data (Board of Estimate) 1929–30—Summer Run-Off 0.7 c. f. s. per Sq. Mile. Squares, Flood; Circles, Ebb; Triangles, All Samples.

In view of the somewhat meager nature of the analytical data, and especially of their uneven and uncertain tidal and seasonal distribution, it seems hardly justifiable to attempt comparisons of the theoretical formula with the actual observed values. It is of interest to note, however, that despite these shortcomings the general picture of the D. O. gradients as computed theoretically is substantially borne out in the analytical results. It seems reasonable to conclude, therefore, that with more evenly distributed and systematic data from the various cross-sections, and with information as to tidal and river volumes at the times of sampling, the formulas for the D. O. gradient through the Bay and up the rivers will be found to be in quite satisfactory agreement with the observations.

The chief practical utility of such formulas is of course in the future planning of remedial works. For this purpose it becomes highly desirable to be able to predict the results in advance. The effect of the removal of 1.1 million contributing population at Wards Island has been thus computed under mean summer flow conditions and 1930 population. At the Narrows the D. O. would be increased from 52 per cent to 61 per cent and at the Battery from 42 per cent to 52 per cent. Similar computations are readily made upon any other assumption as to the location and efficiency of sewage treatment plants. Trial computations also will undoubtedly show the most advantageous points for the treatment of sewage in order to obtain the maximum beneficial results in the Harbor.

Editorial

Chemical Processes of Sewage Treatment

Remarkable interest in the use of chemicals in sewage treatment has developed during the past year. Various new processes of chemical precipitation have been investigated experimentally, and at least one process (Laughlin) has been installed on a large scale for the treatment of the sewage of the city of Dearborn, Michigan. The chemicals used in these processes have usually been lime and iron compounds, although other materials have also been used, such as chlorine, paper pulp, zeolite and copper sulphate. The coagulant in most processes under investigation is ferric hydroxide, produced directly from ferric chloride and lime, or oxidized by air or chlorine from the ferrous condition.

A short review of some of these processes indicates that in most cases further treatment is proposed, in addition to the use of coagulants and sedimentation. This further treatment may be addition of chlorine, use of a rapid sand filter or passage of the clarified effluent through a bed of zeolite. The reason for this further treatment is to obtain a more complete degree of treatment than is possible by coagulation and sedimentation. The goal in some cases has been to equal the removal of B. O. D. by the activated-sludge process, with the hope that the costs of the chemical process will be less. Various ingenious mechanical devices are used in conjunction with some of these processes.

The Laughlin process comprises the addition of lime and ground paper pulp, followed by ferric chloride. A short mixing period is followed by sedimentation in a mechanically cleaned basin, and upward filtration through a peripheral filter of magnetite, which is automatically cleaned by a traveling electro-magnet which lifts the magnetite and allows it to be washed. This process has been described so often in the technical press that a more detailed description is hardly necessary. The results of operation of the Dearborn plant have been awaited eagerly. Several interesting articles have been published by Mark B. Owen, Superintendent of Public Works of Dearborn. Operation at Dearborn has been complicated by the fact that sludge from the East Side Imhoff plant has been introduced into the sewage at the Laughlin plant, consequently the influent has been considerably more concentrated than normal sewage and of a different character. Occasional runs have been made, however, on sewage alone, and such data are valuable as an indication of the efficiency of the process. The use of chlorine as a finishing step has apparently not been of much

advantage at Dearborn, but has shown some benefit in tests of an experimental Laughlin plant at Coney Island.

The Dearborn plant is the only full-scale installation of the various processes using precipitation of ferric hydroxide for clarification, the others operating on a considerably smaller scale.

The Guggenheim process is attracting a great deal of attention at present. (See article by Gleason and Loonam, page 61.) This process has been tested for the past year on Dyckman Street sewage in New York City, and the 25,000 gallons per day plant at the North Side Treatment Works in Chicago will soon go into operation. The feature of this process lies in the use of a zeolite for removal of ammonia and other substances from the clarified sewage. The B. O. D. removals reported for the New York investigations, if confirmed on a large scale, are equal to the best average results obtainable by the activated-sludge process. The regeneration of ferric sulphate and recovery of ammonia are novel adjuncts of this process.

A ferric hydroxide process is being investigated at the Northeast Sewage Treatment Works in Philadelphia, in which ferrous sulphate and lime are used as coagulants, with oxidation of the ferrous to ferric hydroxide by aeration. After coagulation and sedimentation the clarified effluent is passed through a rapid sand filter. A low cost for coagulants is claimed.

The ferric chloride-chlorine process under investigation at Palo Alto, California, is described by Ralph A. Stevenson in this issue, page 53. These experiments started with the intention of using a recirculated chlorinated clay as the clarifying agent, but this was soon abandoned and ferric chloride was used as the coagulant. The recirculation of sludge is an interesting phase of this process, but care must be taken to prevent the sludge from building up an excessive demand for chlorine. No final step has been used in this process, except for the liberal use of chlorine.

Another process quite similar to the Palo Alto scheme has been under investigation by the Diamond Alkali Company, near Cleveland. In this process ferric chloride plus chlorine has been used liberally, followed by filtration through a rapid sand filter, with maintenance of residual chlorine throughout the filter to prevent septicity of the sand bed.

Another chemical precipitation scheme has been under investigation for some time in Ohio, the so-called "Calcar" process. The results of an investigation of this process by the Ohio State Department of Health at Circleville were reported in the 1931 Report of the Ohio Conference on Sewage Treatment. This report is abstracted on page 196 of this issue. This process includes the use of ground marl, in addition to the usual iron and lime.

The use of "home-made" ferric chloride by chlorine plus scrap iron has been studied for some time at the Oklahoma City sewage treatment works by L. H. Scott and others. Use of moderate amounts of chlorine and iron

has been stated to result in greatly improved clarification and improved disposal of sludge.

A number of cities have become interested in the use of ferric chloride for increasing the degree of treatment effected by settling processes, notably during the summer, when insufficient dilution may be available for a settled effluent. This use of coagulants is well worthy of investigation as a possibility of postponing the installation of complete treatment.

The production of ferric hydroxide and its use as a coagulant is the basis of most of the processes just described. A recently reported experimental investigation by the Niersverband in Germany proposed the use of ferric hydroxide produced electrically by electrolysis of iron electrodes. This process appears to be a disinterment of the old Webster process which had a vogue four decades ago. The investigators claim that 50 p. p. m. of iron can be precipitated electrically at about 10 per cent of its cost in ferric chloride, that the electricity can be produced by generators and gas engines operating on the gas from sludge digestion and that the major, if not the only, expense aside from labor is the cost of the iron used for the electrodes plus a small amount of air used for mixing and for oxidizing the ferrous to ferric hydroxide. The necessary settling period is stated to be one-half hour. A removal of only 60 per cent of the B. O. D. is claimed.

The use of electricity in the United States seems to be confined to the Winston-Salem, N. C., plant, where lime is used as a coagulant. This process differs from the German proposal, in that a much smaller amount of electricity is used, but a large amount of lime. The operating results of the Winston-Salem plant have been reported by the Superintendent, Mr. W. E. Thrasher.

The use of chemicals for sewage treatment has been under investigation recently in a small experimental plant at Elmhurst near Chicago. Four chemicals are used, each of which is claimed to be of specific beneficial effect.

This brief review cannot presume to have covered nearly all of the investigations now under way, or the patented processes of sewage treatment that have been developed to include the use of chemicals. What does this activity presage? Will chemical treatment soon fill the gap now existing between plain sedimentation and complete treatment, or will the cost be so great as to offer little advantage over the adoption of complete treatment? Undoubtedly chemical treatment will be developed, and the operating and cost data will follow.

Employment Service

In accordance with the statement on page 1078 of the November, 1932, issue, THIS JOURNAL is offering the use of its pages as an employment service for members of the Federation now unemployed. The following applications have been received. Further information concerning these men can be obtained from the Editor or from Mr. H. E. Moses, Secretary-Treasurer, Pennsylvania State Department of Health, Harrisburg, Pennsylvania.

(1) DESIGNER thoroughly experienced in design and construction of sewage treatment plants. Just completed one year with general contractor on sewage treatment plant job. Previous four years drafting and design work in sanitary engineering. Total experience twelves years since graduation. Age 37. Married. Assoc. Mem. A. S. C. E.

(2) M.S. in SANITARY ENGINEERING, 1932, Michigan State College. Seven years with the Michigan State Highway Commission. Municipal engineering, including construction of water mains and sewers. Assistant instructor in sewage operators school. Publications on trickling filters and stream pollution. Age 31. Married.

(3) SANITARY ENGINEER, graduate M. I. T., four years experience in design of sewers and sewage treatment works, five years experience in investigating industrial wastes, designing and operating sewage testing stations, and investigating and developing methods and apparatus for sewage treatment. Three years as asst. supt. of large activated-sludge plant. Desires position to design or operate treatment works or to aid in the development of new processes and apparatus for sewage treatment. Age 36. Married.

(4) CHEMIST AND BACTERIOLOGIST, university graduate, six years superintendent of water filtration plant, past five years in sewage works laboratory, in charge of plant control. Recent experience in sludge filtration and disposal. Age 37. Married.

(5) SANITARY ENGINEER, M. I. T. graduate, 1927. Formerly connected with large sewage project, in responsible charge of plant operation and large-scale experimental investigations of separate digestion and disposal of sludge. Will accept job as engineer or sanitary chemist. Age 28. Married.

(6) SANITARY ENGINEER, M.S. from Michigan State College. Experience in highway and railway work. University work in soil bacteriology. Age 25. Single.

Proceedings of Local Associations

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Secretary: Jane H. Rider, Tucson.
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Fifth Annual Meeting
New York State Sewage Works Association

New York City, Jan. 17, 1933

The Fifth Annual Meeting of the New York State Sewage Works Association was held at the Hotel McAlpin, New York City, on January 17, 1933. The attendance of 185 at the meeting was the largest ever recorded in the history of the association. At the business meeting Messrs. Edmund B. Besselievre (New York), Henry N. Ogden (Ithaca) and Robert C. Wheeler (Albany) were elected to the Executive Committee in place of Messrs. W. Donaldson, W. A. Ryan and Charles L. Walker whose terms of office expired. Mr. Anselmo F. Dappert of Albany was elected President, and Edmund B. Besselievre, Vice-President. A. S. Bedell, State Department of Health, Albany, was reappointed Secretary-Treasurer.

Following the business session, Mr. Abel Wolman, Chief Engineer of the Maryland State Department of Health, gave a most interesting and timely paper on "Fact and Fancy in Sewerage Financing." This provoked an extended and lively discussion, which was opened by George W. Fuller, Consulting Engineer, followed by H. C. Delzell of the Portland Cement Association. G. W. Jones, Chemical Engineer of the U. S. Bureau of Mines, presented a very valuable and interesting paper on "Explosion and Health Hazards in Sewage Works Operation," supplemented by a practical demonstration of a number of points brought out in the paper. Dr. R. R. Sayers, Chief Surgeon, U. S. Bureau of Mines, and Surgeon U. S. Public Health Service, in his delightful way opened the discussion, dwelling particularly on the physiological side of the problem.

President Earle B. Phelps presided at the luncheon and presented the Kenneth Allen Memorial Award for 1932 to Henry W. Taylor for the most meritorious paper of a technical and research nature presented before the association during the year. George W. Fuller was the principal speaker at the luncheon, using as his theme "Some of the More Important Developments in Sewerage and Sewage Treatment During the Year—What the Future Trends Appear to Be."

The afternoon session was devoted to a paper on "The Development of a Chemical Process for Treatment of Sewage" by George H. Gleason, Chemical Engineer, Guggenheim Brothers, New York City. The discussion was led by Dr. Willem Rudolfs. Following this a non-stop flight was made in busses under police escort to the Guggenheim Laboratories at 202nd Street, to inspect the Demonstration Sewage Treatment Plant, employing chemical purification and filtration, sludge incineration, coagulant re-use and ammonia recovery.

In the evening, the members and guests of the association joined with the

Sanitary Engineering Division of the American Society of Civil Engineers in the annual dinner of the latter. This pleasant custom, started last year, promises to become a permanent feature of the annual meeting. Professor Charles G. Hyde of Berkeley, California, presided as toastmaster and introduced the speaker of the evening, Captain Stanton L. Dorsey of the U. S. Veterans Bureau. Captain Dorsey gave an interesting talk on sewage treatment in Germany, illustrated by motion pictures taken by him on his recent trip to Germany.

A post-convention inspection trip to Freeport, Long Island, was arranged for the day following the annual meeting, bus transportation being furnished by the village officials. Fifty men visited the sewage treatment works of the village, where a plant size experiment is being conducted with the use of ferric chloride as a precipitant in the sewage and to facilitate sludge drying.

The next meeting of the association will be held in Rochester, June 9 and 10, 1933. A. S. BEDELL, *Secretary-Treasurer*

New England Sewage Works Association Annual Fall Meeting

Bridgeport, Conn., Oct. 17, 1932

The Fall Meeting of the New England Sewage Works Association was held Monday, October 17, 1932, at the Stratfield Hotel, Bridgeport, Connecticut. Eighty-seven members and guests were registered for the various sessions of the meeting.

The meeting was called to order at 10:20 A.M. by President Lanphear, who introduced Hon. Edward T. Buckingham, Mayor of Bridgeport. Mayor Buckingham welcomed the Association to Bridgeport expressing the pleasure of the city that the Association had chosen Bridgeport for its meeting.

Pres. Lanphear then introduced Mr. Wellington Donaldson of New York, who presented the first paper at the morning session, entitled "Rating of Sewage Treatment Plants According to Adequacy of Operating Data." The reading of this paper was followed by general discussion from the floor.

Owing to illness, Mr. Michael J. Blew of Philadelphia was unable to be present to read his paper on "Observations on the Incineration of Sewage Sludge," as scheduled on the program. Pres. Lanphear suggested that the time be devoted to a general discussion of the topic. Mr. E. D. Flynn of New York opened the discussion, describing recent experiments on this method of sludge disposal which he had witnessed. Several others participated in the discussion of the very interesting subject.

Following this discussion, the Committee on Sewage Sampling presented its report. This provoked considerable discussion and the committee received valuable suggestions for possible inclusion in its final report which will be presented at the Spring Meeting of the Association.

Pres. Lanphear then opened the session for a business meeting and called upon the Secretary who reported that the membership on October 15 was 141 and that there was a balance of $177.75 in the treasury. The President announced that the Executive Committee is considering holding a two-day session at the Annual Meeting in October, 1933.

Following the business session, the President introduced Mr. J. Frederick Jackson of New Haven who spoke to the members regarding the work of the National Committee for Trade Recovery and the Reconstruction Finance Corporation in relation to self-liquidating public works.

The session adjourned for luncheon, held in an adjoining room of the hotel at 1:00 P.M.

Immediately following luncheon, the members and guests left in automobiles for the inspection trip, visiting the sewage treatment plants at New Canaan, Norwalk and Bridgeport, Conn. These plants proved most interesting, as they represent different types of sewage treatment. In spite of the inclement weather the inspection trip proved enjoyable and profitable.

At 6:30 P.M. sixty-five members and guests sat down to the Association Dinner at the Hotel. Following the dinner Prof. C. E. A. Winslow of Yale University addressed the gathering, his topic being "Sewage Disposal Practice; Historical Development and Current Problems."

The eighth meeting of the Association adjourned at 8:30 P.M.

F. WELLINGTON GILCREAS, *Secretary-Treasurer*

Wisconsin Conducts School for Sewage Works Operators

BY L. F. WARRICK

State Sanitary Engineer

Wisconsin's first school for sewage plant operators was conducted coöperatively by the Hydraulic and Sanitary Engineering Department, University of Wisconsin; the State Laboratory of Hygiene, and the Bureau of Sanitary Engineering, State Board of Health, during the week of January 9 to 14, 1933, at the Hydraulic and Sanitary Engineering Laboratory at the University, with fifteen operators in attendance. The course was sponsored by the League of Wisconsin Municipalities.

Instruction was given in the general theory of sewerage and sewage treatment, maintenance and operation of sewage treatment plants, and measurement of water flow through pipes and open channels and the more common physical and chemical tests to determine efficiency of sewage treatment plant operation. In general the mornings were given over to lectures and discussions, and the afternoons to laboratory work. Abstracts of the lectures were furnished those attending the school.

Topics covered in this short course included the following:

"Aims of Sewage Treatment," by L. F. Warrick, State Sanitary Engineer, Wisconsin State Board of Health.

The First Sewage Treatment Plant Operators School in Wisconsin. Those Operators Attending the School and Several Members of the Instructional Staff Are Shown Above.

"General Theory of Sewage Treatment," by L. H. Kessler, Asst. Professor of Hydraulic and Sanitary Engineering, University of Wisconsin.

"Sewage Plant Control Tests," by M. Starr Nichols, Chief Chemist, State Laboratory of Hygiene.

"Avoiding Odors and Difficulties in Sewage Plant Operation," by O. J. Muegge, Asst. Sanitary Engineer, Wisconsin State Board of Health.

"The Effect of Poor or Inadequate Design on Operation of Sewage Treatment Plants," by W. G. Kirchoffer, Consulting Engineer, Madison, Wisconsin.

"Use of State Laboratory of Hygiene to Sewage Plant Operators," by Dr. W. D. Stovall, Director, State Laboratory of Hygiene.

"Water Measurement," by F. M. Dawson, Professor of Hydraulic and Sanitary Engineering, University of Wisconsin.

"Sewer Rental Laws and Their Use," by L. F. Warrick.

"Sludge Problems," by E. J. Beatty, Asst. Sanitary Engineer, Wisconsin State Board of Health.

"Effect of Industrial Wastes on Sewerage Works Operation," by L. F. Warrick.

"Use of Chlorine in Sewage Treatment," by C. O. Bruden, District Representative, Wallace & Tiernan Company.

"Sewage Plant Records," by E. J. Beatty.

"History of Sewage Treatment," by J. E. Bowman.

Instruction Was Given in the Laboratory on Methods Used for Control of Operation of Sewage Treatment Plants.

Discussions and demonstrations of sewage plant control tests were conducted throughout the course by Mr. J. M. Holderby, Assistant Sanitary Engineer, Wisconsin State Board of Health, and Mr. H. W. Ruf, Instructor, Sanitary and Hydraulic Engineering, University of Wisconsin. A visit to the sewage treatment plants in Madison was conducted by Mr. John Mackin, Superintendent of Sewage Treatment for the City of Madison. The accompanying photographs shows the school in session in the Sanitary Engineering Laboratory.

The course of instruction was concluded with a dinner attended by thirty-one persons, held at the University Club. Short talks were given by Dr. C. A. Harper, State Health Officer; Dean F. E. Turneaure of the

College of Engineering; F. M. Dawson, Professor of Sanitary and Hydraulic Engineering, University of Wisconsin; L. F. Warrick, State Sanitary Engineer; and G. C. Younkers, Superintendent of the Hartford sewage treatment plant. The principal speaker of the evening was Adolph Kanneberg, Chairman of the State Committee on Water Pollution, who talked on "Wisconsin's Waters." Certificates of attendance were presented by Dean F. E. Turneaure.

The total cost of the course per man, exclusive of transportation to and from Madison, was twenty-five dollars, which included room, board, registration and laboratory fees. In view of the benefits afforded by the school as part of the program to improve the operation of Wisconsin's sewage treatment plants, it is contemplated that the school will become an annual event.

Michigan State College Offers Laboratory Course for Sewage Works Operators

BY FRANK R. THEROUX

Asst. Professor of Civil Engineering

Michigan State College, Civil Engineering Department, is now offering an annual short laboratory course in sewage analyses. This course is suited to the practical sewage works operator who may have only a very limited knowledge of chemistry. It is in addition to regular college courses offered for students in sanitary engineering.

The work is given in the new sanitary engineering laboratory, which was opened in the Fall of 1931. The laboratory is completely equipped for chemical analyses of sewage, water and industrial wastes. It is also used for students in sanitary engineering and for experimental and research work carried on by students for advanced degrees and by the Engineering Experiment Station. The accompanying picture shows the general arrangement of the laboratory.

The first work offered for sewage works operators was a two-day course on March 29 and 30, 1932. These dates immediately preceded the conference of the Michigan Sewage Works Operators Association held March 30 and 31. In this way it enabled many of the operators to attend both the short school and the conference. The enrollment in the course was larger than expected and due to the limited facilities a number of applicants were asked to defer the work until later. Twenty-two men took the course, mostly Michigan sewage works operators, although there were some sanitary engineers and others interested in sewage works operation.

The degree of previous training in chemistry varied greatly among those taking the course. Some had had no previous chemistry in school and others had taken a considerable amount of college chemistry. Explanations and lectures were offered on the basis of no previous training by the

Sewage Laboratory, Michigan State College, East Lansing.

students. Definite written instructions were given to each student showing the steps in order for each determination. The results were very satisfactory.

The work offered consisted of the following:

I. Solids Determination
   (1) Total Residue (Total Solids)
   (2) Loss on Ignition
   (3) Suspended Solids
      a. Total
      b. Loss on Ignition
   (4) Settleable Solids.

II. Oxygen Determination
   (1) Dissolved Oxygen
   (2) Biochemical Oxygen Demand
   (3) Oxygen Consumed
   (4) Relative Stability.

III. Nitrogen Determination
   (1) Nitrogen as Free Ammonia
   (2) Nitrogen as Nitrites
   (3) Nitrogen as Nitrates
   (4) Total Nitrogen.

A similar course of instruction will be offered this year on March 28

and 29, which dates immediately precede the Michigan Sewage Works Operators Conference to be held March 30 and 31. No tuition is charged. A certificate will be given to each person who satisfactorily completes the course outlined.

A manual of laboratory instructions for sewage analyses is being prepared and printed copies will be ready for distribution before the dates of the conference. This manual will contain detailed methods for the usual chemical and bacteriological tests made in sewage works laboratories.

The laboratory work is given under the direction of E. F. Eldridge, Research Assistant, Engineering Experiment Station, and Frank R. Theroux, Assistant Professor of Civil Engineering. Inquiries regarding this work should be addressed to Prof. Theroux, Michigan State College, East Lansing, Michigan.

Reviews and Abstracts

H. W. STREETER

Activated Sludge—A New Process for Partial De-Watering and Subsequent Disposal

By Herbert D. Bell

Résumé of a paper read at the Annual General Meeting of the Association of Managers of Sewage Disposal Works, Nov. 17, 1932, together with discussion. *The Surveyor*, **82**, 507-8, 517-8 (Dec. 2, 1932).

The difficulty of separating the solid matter in activated sludge from its contained water has retarded the more general use of this method of sewage disposal. De-watering on drainage beds results in nitrogen losses owing to the changes in form of the organic matter during the drying period with consequent deterioration in fertilizer value of the sludge. Sludge pressing fails to yield a satisfactory cake because of the spongy nature of the sludge solids. Moreover, with the possible exception of the acid and chalk process, chemical treatment has given no tangible results of success when applied to large-scale plants.

Barnsley Experiments in Sludge De-Watering.—In view of the above difficulties, experiments have been conducted at Barnsley to discover some improved means of reducing the water content of activated sludge before its final disposal. Drainage on beds, return of the activated sludge to the incoming sewage, plowing under on land, and chemical treatment were some of the procedures tried out with unsatisfactory results. As a result of these failures, the author concluded that the problem was a physical rather than a chemical one. Chemicals increased the specific gravity of the liquor and hence retarded settlement of the solid particles, consequently the remedy was either lowering the specific gravity of the liquor or weighting the sludge solids. The former procedure proving unsuccessful, attention was directed toward making the solid constituents heavier.

Clay as a Coagulant.—Experiments with various kinds of clay indicated that those containing gritty matter effected greater clarification than comparatively pure clay. Later, gritty substances were tried until one was found which readily separated 50 per cent of the liquor in one hour settling compared with from 8 to 10 per cent of the untreated sludge. Varying amounts of this coagulant were tested and it was noted that immediately after mixing with the sludge, clotting action set in throughout the whole

mass, and that these clots in falling to the bottom gradually displaced the liquid until two distinct layers were formed. The upper clear liquid increased in volume as settlement continued up to three hours and ranged from 55–65 per cent of the whole in comparison with 10–20 per cent for the untreated portion. It was observed that if with certain substances no clotting effect occurred, no great separation of liquor and solids followed. Furthermore, certain materials having apparently the same composition and density acted very differently in their coagulating power.

Sand as a Coagulant.—This difference in the clotting ability is illustrated in the case of two samples of sand of about the same density, grading and composition, in which immediate coagulation was produced by one and very little by the other when mixed with equal volumes of sludge. On repetition of the experiment but with these sands previously washed and dried, the first gave almost exactly similar coagulation and the second none at all, having lost the little power it exhibited in the unwashed condition. On comparing the two washed sands, the one which possessed the clotting power was found to be composed of sharp pointed grains while the other had smooth rounded grains. Re-examination of the various substances used in previous experiments disclosed that all of them which caused rapid separation of liquor and solids invariably had a sharp rough surface while less effective materials had more rounded and smooth surfaces. It was evident therefore that washing the smooth-grained sand had removed some foreign matter which had given it a somewhat roughened exterior.

Conclusion from Experiments.—As a result of these and other tests, the author concluded:

(1) The type of substance which will produce coagulation of the particles of activated sludge is one which is insoluble in water, is slightly heavier than water, and whose surface is coarse, rough or sharp pointed.

(2) The type of substance which produces no coagulation with activated sludge is one which has a smooth and rounded surface (even if insoluble in water) and of a higher specific gravity than that which is in the preceding category.

Further experiments demonstrated that exactly similar results were obtained with samples of activated sludge from other treatment plants. The conclusions of Clifford and Windridge were confirmed (cf. SEWAGE WORKS JOURNAL, Sept., 1932, pp. 906–10) that wider diameter vessels give proportionately larger volumes of supernatant liquor, even when the activated sludge is mixed with a coagulant. It appears also that the coagulants with the higher specific gravities generally produce the smaller volumes of separated liquor. This, the author believes, is because the material with the lower specific gravity has more particles per unit of weight which form nuclei for the activated sludge floc. There are exceptions to this rule, however—in the case of coke breeze, for example, where it is be-

lieved the pores of the coke becomes sealed by the sludge and the entrapped air buoys up the particles and causes them to float rather than sink.

This clotting effect with material of suitable surface contour follows, almost, the laws of a quantitative physical reaction. When the correct amount of coagulant is added with resulting clotting, a further amount exerts no further clarification, but drops to the bottom, inert, while proportionately smaller amounts than the optimum separate correspondingly smaller volumes of liquor and sludge.

From previously presented observations on the capacity of a sand drying bed for de-watering sludge and from the experiments described above, the author suggests the following laws may be derived:

(1) Sharp and rough surfaces attract light solids suspended in an aqueous liquor and repel water.

(2) Smooth and rounded surfaces attract moisture and repel solids suspended in an aqueous liquor.

Further experiments using alumina floc instead of sludge and rough surfaced inert materials gave similar results, that is separation was accelerated by the addition of the substances of prescribed surface contour.

In conclusion the author points out that:

(1) Separation of at least two-thirds of the original water content in activated sludge can be effected in three hours or less, by mixing the sludge with materials whose particles present a rough surface and allowing suitable opportunities for settlement.

(2) The deposit remaining after liquor has been drawn off readily responds to the loss of more moisture on drying beds similar to those used for ordinary tank sludge, and

(3) The cake so formed on the drying bed will continue to lose still more of its moisture on transference to dumps, and like ordinary tank sludge under similar conditions can be reduced to a powder by pulverization. Thus it should now be possible, by means of suitable coagulants, to give to the final powdered product some proportion of other plant foods, which though diluting to some extent the original nitrogen content, may give a fertilizer of such a nature as will find a ready sale.

By these means, the early pioneers of the activated-sludge process may be able to realize their expectations in the production of a manure from sewage with a marketable content of nitrogen and other plant foods.

Discussion.—Mr. W. T. Lockett, in opening the discussion on the paper, stated that the experiments gave no evidence of successful handling of the sludge de-watering problem, and the idea of adding relatively heavy and coarser particles of material to activated sludge to aid de-watering was not new. One way of doing this was to add surplus activated sludge to crude sewage and settle the mixture in sedimentation tanks. The fertilizing value of sludge to which inert materials are added is further reduced,

making it more difficult to compete commercially with the synthetic fertilizers now being manufactured. At present he believed that digestion was the most promising solution of the sludge problem.

Mr. W. Clifford took issue with the author's statement that the addition of soluble chemicals necessarily increased the specific gravity of the liquid and retarded settling. In experiments in which sodium chloride and various other salts were added to activated sludge, he had found the rate of settlement to be improved by alteration of the pH value and perhaps the electrical charge of the flocs.

Mr. C. Sams questioned the value of activated sludge as a fertilizer and expressed the view that studies should be devoted toward improving methods of final disposal and not de-watering of the sludge.

Mr. P. G. Lloyd disagreed with the views of Mr. Sams regarding the fertilizing value of sludge and offered his experience at Kingston to prove his point that, if properly advertised and marketed, a continuous demand could be maintained for the product. He disapproved of the addition of inert materials which lower the nitrogen value.

Dr. H. Kessener called attention to his previously expressed suggestion for improving the fertilizing value by the addition of carbonate of lime and phosphate of lime to activated sludge, which might aid de-watering.

The Chairman found it difficult to understand why rounded surfaces had the directly opposite effect of sharp rough ones on the rate of de-watering, and suggested the necessity of further experimental work. He also inquired as to the optimum amount of inert material to be added and the possibility of using residue from house refuse as the coagulating medium.

Mr. J. H. Spencer stated that the sharp gritty particles penetrated the semipermeable membrane surrounding the floc masses, thereby resulting in more efficient coagulation.

Mr. C. T. Howard Humphreys expressed his scepticism of the fertilizing value of activated sludge and the probability of its competing with commercial fertilizers, although he favored the activated-sludge method of sewage treatment in proper conditions.

In closing the discussion, the author stated he had found that the smaller the particles, provided they were of regular surface, the greater the proportion of separated liquor was obtained. During the course of the experiments which had extended over a period of three years, the optimum amount of inert material added had been reduced until at the present time there was 55 per cent of the original activated sludge in the finished product.

J. K. HOSKINS

The Disposal of Activated Sludge

BY ARNOLD KERSHAW

The Surveyor, **82**, 427–8 (Nov. 14, 1932)

The experiments and finally adopted method for final disposal of sludge from the activated-sludge plant at Epsom, England, are discussed in this paper read at a meeting of the Association of Managers of Sewage Disposal Works held at London on November 5, 1932.

The excessive amounts of sludge to be dealt with resulting from the activated method of sewage treatment are emphasized. This greater sludge volume is due to the higher water content of such sludge and presents one of the difficulties of its disposal. Such sludge, moreover, must be exposed to the air in very thin layers on the disposal area to facilitate drying and prevent aerial nuisance.

The Epsom plant, employing the Simplex surface aeration method of sewage treatment has about 11,000 gallons of surplus activated sludge to dispose of every other day, with a water content of from 98.5 to 99.5 per cent. This material is pumped through a sludge main and discharged through 5 valves onto a 3-acre plot of land roughly rectangular in shape. The first method of disposal was to plow and ridge the land and discharge the sludge to the furrows. Because of the sloping ground ponding could not be entirely prevented. Also the sludge, because of its finely divided character, made an almost water-tight cover which prevented downward filtration of the contained water. The resulting slow drying caused trouble from odors and flies before the ground was dry enough to permit covering the furrows. After six months of use the first furrows were scarcely dry enough for replowing.

The next method tried was to discharge the sludge on the land that had been previously harrowed. Although a slightly more uniform distribution of sludge was obtained the slope of the ground caused too rapid run-off of water with much contained solids.

Following these experiences about half the land area was plowed up and seeded with coarse water grass. When a strong growth about one foot high had been obtained, activated sludge was discharged on to it with satisfactory results. The root growth held back the solids and the grass provided an effective shade with little trouble resulting from offensive odors or flies. This method was later applied to the whole 3-acre area, one section being allowed to rest while the other is in use. The grass grows well at all seasons and breaks down and smothers the accumulated deposits of sludge.

Further experiments are described employing deep trenches and drying beds. The trenches when new permitted rapid seepage of the supernatant

water through the trench sides but after several refillings with sludge the water content did not separate quickly and would have soon clogged completely. Filling and retrenching between the original channels was not effective and resulted in water-logged soil. The tests of drying beds from which the supernatant water was periodically decanted were somewhat more successful if the wet sludge layer on the bottom, after decantation of the supernatant water, was not more than $1^1/_2$ inches in depth. With greater depths of dewatered sludge resulting from repeated fillings, great difficulty was experienced with drying. A further experiment indicated that a mixture of detritus sludge and activated sludge decanted in the same way, dried almost as well as activated sludge alone.

The author concludes that discharge of activated sludge on grass land, worked in sections, is a cheap method of disposal and one which gives very little trouble from offensive odors and flies. J. K. HOSKINS

Experiences with Artificial Heating of Digestion Tanks in the Treatment Plant of the City of Halle

BY PROF. DR. ING. HEILMANN, HALLE

Gesundh. Ing., **55**, 463 (1932)

Digestion, as all biological processes, is dependent upon the temperature. For ordinary digestion, optimum temperature seems to be about 82.5° F. and for thermophilic digestion from 113–131° F. Sludge may be heated either before it arrives at the digestion tank or in the tank itself and it may be heated directly or indirectly. The direct addition of hot water or steam to the sludge has the advantage of more rapid distribution of heat but it has the disadvantage of dilution of the sludge. The use of jackets or coils as heating surfaces makes possible a better and more uniform distribution of the heat. The coils may be placed on the bottom, as in Halle, around the vertical walls or suspended in the upper part of the digestion room. This last type has the advantage of being removable for frequent cleaning so that the sludge crust which forms on the heating surface can be scraped off. The disadvantage is that its location in the upper part of the tank leaves the lower part of the tank cold and circulation of the sludge is required so as to bring the cold bottom sludge in contact with the heating coils. Circulation also aids in breaking up the scum. The heating coils on the vertical wall are more advantageous but horizontal stirring is necessary for the distribution of heat.

No mechanical circulation is necessary when the heating coils are placed on the bottom. The warm sludge rises to the top, loses its gas and sinks to the bottom. In this way the entire contents of the digestion room are

heated. The disadvantage of this system is that there is no distinct separation between sludge and the liquor. Although the coils are inaccessible unless the tank is completely emptied, experience at Halle has shown that cleaning or repairing is very seldom necessary.

The two secondary digestion tanks in Halle, with a capacity of about 35,300 cubic feet each, are equipped with heating coils placed in the bottom. These coils are heated with hot water.

In secondary digestion tank I 985 feet of copper pipe, in four sections, are placed about 5 inches above the bottom in the form of an Archimedes spiral. The total heating surface in this coil amounts to 264 square feet. Copper boilers which did not prove satisfactory because of the excessive corrosion were replaced with a cast-iron boiler.

In secondary digestion tank II provision is made for thermophilic digestion. Two cast-iron boilers, with temperature automatically maintained at 194° F., are operated in parallel. As in digestion tank I the heating coils are arranged in the form of an Archimedes spiral, about 10 inches above the bottom of the tank. The pipes are made of copper, tinned on the outside. The length of the coil is 1970 feet and the heating surface amounts to 1076 square feet. In digestion tank II the distance between the pipes is 1.18 feet whereas in digestion tank I the distance is 3.6 feet.

In general, the heating plant is in operation continuously except for very short periods during servicing of the motor and equipment.

The heating plant of secondary digestion tank I has been in operation more than 2.5 years. The coefficient of heat transmission of the water to the sludge has remained on the average at about 50–60 kcal. per square meter per hour for 1° C. drop in temperature. In general, the average hot water temperature varies between 122–140° F. Occasional raising of the temperature to over 158° F. has caused no change in the coefficient of heat transmission.

In secondary digestion tank II, which had been designed for thermophilic digestion, the coefficient of heat transmission gradually decreased to 15. The heating equipment therefore was insufficient. This low coefficient of heat transmission was probably due to the formation of an insulating crust of sludge on the heating coils as a result of the high temperature of 176° F. Interruption of operation or use of lower temperature did not raise the coefficient of heat transmission.

The results indicate that at a hot water temperature of 140° F. a coefficient of heat transmission of 50 may be attained and at 176° F. a coefficient of only 15 resulted. Part of this difference may be due to the fact that the pipes in digestion tank I are copper whereas in digestion tank II the copper pipes are coated with tin. The smaller distance between the pipes may decrease the efficiency.

After a year's operation secondary digestion tank I was emptied and a coating of sludge 3–5 mm. thick was found on the pipes. Since the coefficient of heat transmission for digestion tank I has not changed we may assume in digestion tank II, that, with a coefficient of only 15, the sludge layer must be 6–10 mm. thick. So far there is no apparent advantage of the tinned pipe over the copper pipe.

From this work we can conclude that some other method of heating must be employed for thermophilic digestion, since an increase in the size of the heating surfaces would make the pipes so close together that they would form an almost continuous heating surface.

The sludge added to the secondary digestion tanks was obtained from the Imhoff tanks and consisted of scum as well as settled solids. Investigations over the last two years have shown that the scum has an average composition of 90 per cent water, 64 per cent organic matter on dry basis and the pH value is 6.8. Settled solids contain 94 per cent water and 57 per cent organic matter on a dry basis, with a pH of 6.9. The sludge drawn from the two secondary digestion tanks contains 94 per cent water and 52 per cent organic matter on dry basis. The pH is 7.4. From these values it may be seen that the water content of the sludge is not changed in the secondary digestion tanks. There is no separation of sludge and water because the entire contents of the digestion tank are in constant motion due to the effect of the heat. However, the organic matter is reduced from 57 to 52 per cent.

The scum forms only when the heating plant is out of operation for some time. When the heating plant is again put into operation the scum disappears.

Before the construction of the secondary digestion tanks about 19,768,000 cubic feet of gas were obtained from the Imhoff tank. It was estimated that the two secondary digestion tanks would yield about 7,766,000 cubic feet of gas per year. From June 1, 1931, to May 31, 1932, 34,250,000 cubic feet of gas were obtained from the Tafelwerder treatment plant. This excess of more than 14,482,000 cubic feet is due to the secondary digestion tanks. Considering the fact that digestion tank II was operated less than a year, we may expect in the coming year a yield of about 35,300,000 cubic feet. Based on a population of 190,000, last year 180 cubic feet of gas per capita per year were obtained. Of the 34,250,000 cubic feet, about 16,600,000 cubic feet were obtained from the Imhoff tank, 6,350,000 from secondary digestion tank I and 11,300,000 from digestion tank II. The temperature in digestion tank II was maintained at about 82.5° F. whereas in digestion tank I it varied between 71.5° and 77° F. Discontinuance of heat in digestion tank II caused the gas yield to be reduced one-half. Since the stirring action due to the heating is necessary, the heating plant has run continuously even though the temperature of 82.5° F. was exceeded.

A good picture of the efficiency of the digestion tanks is obtained by comparing the gas formed per cubic foot of added sludge. In secondary digestion tank I, during one year, 791,000 cubic feet of sludge formed 6,350,000 cubic feet of gas or 8.1 cubic feet per cubic foot of sludge; in digestion tank II 911,000 cubic feet of sludge produced 11,300,000 cubic feet of gas or 12.4 cubic feet of gas per cubic foot of sludge; in comparison with this, 1,700,000 cubic feet of sludge in the Imhoff tank produced 16,600,000 cubic feet of gas or 9.7 cubic feet of gas per cubic foot of sludge.

The effect of heating is clearly shown when the gas yielded per cubic foot of digestion space of the secondary digestion tanks is compared with that from the Imhoff tank. The Imhoff tank with capacity of 191,000 cubic feet handled 1,700,000 cubic feet of sludge or 9 cubic feet of sludge per cubic foot of digestion space. Secondary digestion tank I of 38,100 cubic feet capacity handled 791,000 cubic feet of sludge or 20.7 cubic feet of sludge per cubic foot of digestion space. Secondary digestion tank II with a capacity of 44,800 cubic feet handled 911,000 cubic feet of sludge or 20.3 cubic feet of sludge per cubic foot of digestion space. The two digestion tanks were loaded more than twice as heavily as the Imhoff tank. Nevertheless, digestion tank I yielded 167 cubic feet of gas per cubic foot of digestion space and digestion tank II yielded 255 cubic feet in comparison with 87 cubic feet from the Imhoff tank.

The average analysis of the gas is:

Methane	69.8%
Carbon dioxide	20.0%
Nitrogen	1.1%
Hydrogen sulphide	.1%

In secondary digestion tank I 1,483,000 cubic feet of gas from the 6,350,000 cubic feet collected or 23.3 per cent were used for heating. In digestion tank II 4,236,000 of the 11,300,000 cubic feet or 37.5 per cent were used for heating. The excess from digestion tank I is 4,870,000 cubic feet and from digestion tank II 7,060,000 cubic feet. G. P. EDWARDS

Sewage Disposal for the City of Magdeburg

BY MUNICIPAL SURVEYOR NADERMANN AND DIPL.-ING. STRUMPFEL, MAGDEBURG

Gesundh. Ing., **55**, 367, 384 (1932)

Although several projects for sewage disposal were considered previous to 1914, war conditions made their postponement necessary. In the years immediately following the war, need for clarification became even greater because of the increased amount of sewage resulting from the expansion of

the sewerage system. There were three possibilities for treating the sewage:

(*a*) The present sewerage system to the sewage farm could be used and the additional sewage treated in a special treatment plant before being discharged into the Elbe. Annual expenses including interest on capital and operating expenses would amount to about $90,000.

(*b*) The sewage farm could be abandoned and the sewage discharged after the treatment into the Elbe. Annual expenses including interest on capital and operating expenses would amount to about $40,000.

(*c*) The sewerage system could be enlarged so that it would carry all the sewage to the sewage farm, where it could be treated. Annual expenses including interest on capital and operating costs would amount to about $150,000.

After due consideration it was decided to abandon the sewage farms and, after suitable treatment, discharge the sewage into the Elbe. Construction was begun in the fall of 1924, and in the spring of 1926 the new plant was ready for operation. The sewage passes through coarse and then fine screens to the Elbe at the rate of about 50 cubic feet per second. The maximum dry weather flow is diluted from 100–3700 times in the Elbe. Numerous investigations of the Elbe have shown that the addition of Magdeburg sewage has had little effect on the stream in chemical and biological respects although bacteriologically the stream is in poorer condition. Chlorination apparatus is provided for disinfection purposes during epidemics. For about 315 days per year sewage can flow directly into the Elbe and the remainder of the time the river is so high that the sewage must be pumped. The abandoned sewage farm was leased for cultivation, reforested or allowed to lie fallow.

At first the screenings were plowed into sandy fields. This was not satisfactory because the high paper content caused the soil to become matted. Experiments using these solids as fertilizer were not successful. It was found that mechanical circulation was necessary for satisfactory digestion because the sludge balls which formed did not digest well. The screenings, mixed with canal water when necessary, are forced about 410 feet through a special conduit to a digestion tank fitted with sludge circulating apparatus. The gas formed is used for heating the tanks. Digestion space of only 0.366 cubic feet per capita was allowed, giving a total capacity of 106,000 cubic feet. An old experimental tank was enlarged to serve as a digestion tank. It was decided to increase the size of the old tank by building partly above ground because it was expected that the cold ground water would cause high heat loss. Great care was taken to strengthen the walls and to make the joints between the old and new structures tight.

The tank was divided into two equal parts by a reinforced concrete wall.

To avoid loss of gas the gas domes were covered with a layer of lead 1.5 mm. thick, fastened between two layers of wool felt. A layer of pumice concrete about 4 inches thick was used to protect the lead and wool felt layer as well as to decrease heat losses in the digestion tank. The sloping roof was covered with about 16 inches of earth and the concrete portion of the roof was covered with 0.80 inch of asphalt.

The protection against loss of heat was so satisfactory that during the winter months, with an outside temperature between 32° F. and 41° F., the temperature in the tank was lowered only from 79° to 64.5° F. over a period of sixty days, with no artificial heat added. During the summer months, the temperature was maintained almost constantly at 70° F. The fresh solids are forced by compressed air to a small tank situated over the center of the digestion tank. This small tank is so constructed that it permits the escape of the compressed air and the sludge is fed from it into the two sections of the digestion tank. The supernatant liquor is withdrawn from the end of each digestion tank. Eight screw pumps are provided to circulate the sludge and thoroughly mix it, breaking up all sludge balls. Although provision was made for adding warm canal water in order to heat the tanks this has been used only at the coldest times of the year. The gas from the digestion tanks is collected in a gas tank of 3500 cubic feet capacity.

The costs of the plant amounted to:

Sewage purification plant (buildings including machines, etc.)	About	$78,250.00
Effluent canal to the Elbe	About	88,250.00
Chlorination plant	About	3,500.00
Plant for the fresh sludge removal	About	10,000.00
Digestion tanks	About	45,000.00
Plant for gas utilization	About	6,250.00
Total	About	$231,250.00

Shortly after the digestion tank was put into operation it was necessary to add about 2.2 tons of lime in order to overcome acid digestion. The pH was about 7.0–7.2. Very soon the very heavy scum formation and the large amount of rags, which wound around the sludge circulating machinery, caused further difficulty. Changes were made in the screw pump which permitted subsequent satisfactory operation. The scum was successfully broken up by the circulating apparatus. The digested sludge is drawn onto the drying bed in the usual way. Organic matter of the fresh solids has been reduced 40–55%. Dried sludge was removed from the beds, mixed with peat dust and spread on land. It must be remembered, when comparing with other plants, that the composition of the solids is different from that of ordinary settled sludge. The screenings do

not contain fine colloidal material and other easily digestible substances. Accordingly the gas yield is less than from settled sludge.

The composition of the gas is as follows:

Carbon dioxide	22.0%
Methane	60.8%
Oxygen	2.5%
Nitrogen	13.4%
Other hydrocarbons	1.3%

In Magdeburg the gas obtained and its utilization are very important but more important is the satisfactory disposal of the sewage solids.

G. P. EDWARDS

Control of the Sewage Filter Fly (Psychoda)

BY W. D. SCOULLER AND H. H. GOLDTHORPE

The Surveyor, **82**, 475–6, 481–2 (Nov. 25, 1932)

This paper, read at the annual general meeting of the Association of Managers of Sewage Disposal Works presents the results of experiments on both a laboratory and plant scale, for the control of filter flies as conducted at the Huddersfield, England, sewage treatment works.

Laboratory Experiments.—Laboratory experiments, employing a battery of small sewage filters, were designed to test the relative effectiveness on fly breeding of such substances as gas works distillates, petroleum, base oils and orthodichlorbenzene. These materials were diluted with sewage and applied to the filters for periods of 15 minutes, after a prior period of rest of 30 minutes and a subsequent rest of one hour. Suitable substances would kill all the flies in 15 minutes. A new crop would appear next day so that treatment was continued daily until no flies appeared next day, this period depending on the temperature which influences the life cycle. Afterward single treatments at intervals kept the flies under control.

In these tests petroleum base oils were not very active, gas distillates when tar acids were present gave good results and orthodichlorbenzine was very active. A daily dose of creosote for 25 days and one thereafter every 14 days controlled the flies.

Filter Plant Treatment.—Following the satisfactory results obtained in the laboratory tests, creosote emulsion was applied to the 10 acres of filters in 1931, a wet year, and again in 1932, a dry one. The total days on which the emulsion was applied was 57 and 51, respectively, with corresponding days of no treatment of 65 and 76. The initial period of daily dosing was 39 days in 1931 and 31 days in 1932. During both these years flies were kept under control. Temperature exerts a considerable influence on fly breeding, no trouble being experienced until the temperature exceeds 50° F.

The life cycle of the fly also varies with temperature as indicated by the following results:

Temp.	Life Cycle Period (Days)	Remarks
80° F.	7 to 8	Flies about half normal size
65° F.	14	Flies slightly under normal size
50° F.	30	

Observations showed that most of the creosote is absorbed by the filter slime and that its presence in the effluent disappears in one hour. No adverse effect on the quality of filter effluent could be detected.

Manufacture and Application of Creosote Emulsion.—The creosote used was a local product containing about 18 per cent by volume of tar acid. The emulsion is composed of one volume of the creosote in an equal volume of a 5 per cent aqueous solution of soap. It is made by mixing together 20 gallons of creosote with 14 lbs. of grease recovered from the sewage to which is later added 19 to 21 gallons of a 1 per cent solution of soda ash, the whole being mixed to an emulsified condition.

This emulsion, stored in barrels, is added through a short india rubber connection to the inlet valve of the filter and thus mixed with the filter influent, in which diluted condition it is sprayed over the filter surface for a period of 15 minutes. One gallon of the creosote covers 175 sq. yd. in a concentration not exceeding one-half of one per cent. The filters are allowed to stand idle one hour before and after the treatment is applied when this is possible. The cost per acre per year was £53–11–6 in 1931 and £41–3–10 in 1932.

General Observations.—The creosote treatment does not kill the egg, larva or chrysalis of the fly and consequently the first stage of daily treatments is designed to cover the period of its life history. This first treatment is delayed as long as possible in the spring to permit unloading of the filters and thereby avoid ponding. Treatment is likewise discontinued as early in the fall as possible to avoid checking of the summer unloading. The toxic agent in the creosote is believed to be the vapor from the tar acids.

Discussion.—Mr. J. T. Thompson (Leeds) suggested that the enormous fly population at the Huddersfield plant might be a result of the open walls of the filters and the use of clinker as a medium. At Leeds where the filter walls were of solid brick and the medium a rounded water worn gravel very few flies were produced. Moreover, at Leeds the whole filter surface was wetted which appeared to check the migration of the flies. He suggested also that the condition of the filter influent might have some effect on the extent of fly production.

Mr. J. P. Todd (Ashton-under-Lyne) related unsuccessful efforts to control Psychoda production by the use of chlorine up to concentrations of

50 p. p. m. following which the orthodichlorbenzine treatment as recommended by the author proved effective, at a cost of 3.34 d per sq. yd. It was observed that the Psychoda were more numerous on the filters with the coarse medium.

Mr. Albert Harman stated that the fly should be controlled in the larval stage which could be done by flooding the filters for a time. This procedure shut off the air supply of the air breathing larva and destroyed them.

Mr. J. H. Garner described his previous work at Huddersfield in controlling Psychoda in which he used creosote sprayed on the filters. He ascribed the high fly production to the coarse nature of the filtering medium and the nature of the tank effluent which contained large quantities of soapy textile wastes which served as food for the larva. He observed that flies were most numerous in heavy, moist, warm weather especially after thunderstorms. He advised the provision for filter flooding in new construction for fly control.

Mr. J. B. Croll had experienced the fly nuisance at Richmond when a change from contact beds to sprinkling filters was made. Flooding the filters once each week had been effective in controlling the flies and new filters were being constructed to permit flooding.

Mr. Scouller, in replying to the points raised in the discussion stated that he did not believe the existence of Psychoda was related to the existence of open filter walls, because the flies bred on the filter surface. He agreed, however, that the size of clinker had a great deal to do with fly breeding. He doubted the efficacy of wetting down filters comprised of coarse clinker. He reiterated the ineffectiveness of naphthalene in fly control as demonstrated by thorough tests, as well as of chlorine in small quantities. He had concluded that orthodichlorbenzene was better than creosote as stated by Mr. Todd. The flooding procedure was not practicable at the Huddersfield plant.

J. K. HOSKINS

The Effect of Iron on Sewage Purification

BY W. D. SCOULLER AND J. H. SPENCER

Presented at the Annual General Meeting of the Association of Managers of Sewage Disposal Works, November 17, 1932. Résumé in *The Surveyor*, **82**, 476 (Nov. 25, 1932)

The results of experiments carried out at Huddersfield in 1927–28 on the influence of iron on sewage treatment are presented in this paper. The tests were made by aerating mixtures of domestic sewage free from iron with sludge developed by aerating it with domestic sewage, changed daily, over a period of five weeks.

These mixtures were aerated for about one day in bottles containing 90

ml. of the sewage liquor and 150 ml. of the sludge from the preceding day's working. Following aeration the mixtures were allowed to settle for 1 and 2 hours in liter cylinders for observation of the sludge volume. These tests were run in parallel, to one of which a daily dose of iron increasing gradually from 10 to 100 p. p. m. was added over a period of three months. The iron was added as a ferrous sulphate solution in the proportion of 1 gram of ferrous iron in 100 ml. The solution also contained one ml. of concentrated sulphuric acid in 100 ml. to maintain the iron in the ferrous state.

The results obtained from these experiments are presented in the form of a tabulated summary of weekly averages. Both series indicated good purification, with the iron containing one showing somewhat the best until a concentration of 100 p. p. m. of iron had been reached, except that smaller nitrification was obtained, the production of nitrates steadily decreasing to zero as the iron dose increased.

When 100 p. p. m. of iron were added, the efficiency of purification was decreased, iron appeared in filtrable solution in both the ferrous and ferric condition and the liquid became definitely opalescent instead of clear. Conditions improved when the dose was reduced to 80 p. p. m., but again became worse and definitely remained so when the 100 p. p. m. rate was resumed. The production of nitrates ceased entirely although purification was satisfactory so far as organic content of the sewage was concerned. The sludge which had previously settled more rapidly lost this power when the iron dose was 100 p. p. m. The experiments were continued with a reduced iron dosage to determine if this deterioration was temporary or whether the sludge was permanently impaired.

Conclusions.—The conclusions as stated by the authors from these experiments are as follows:

"(1) Iron in practically occurring concentrations will not interfere with sewage purification, beyond inhibiting or entirely preventing nitrification. In other respects the presence of iron is advantageous.

"(2) Above a critical concentration of 10 parts per 100,000, iron definitely impedes purification by activated sludge, but

"(3) It does not render the sludge incapable of recovery, when the iron dosage is reduced.

"(4) To effect the best recovery the change back to good working conditions must be gradual."

This last point seems to be a fairly general application. It has often been stressed with respect to gas liquor and other trade effluents than iron. Sudden changes from bad to good may be just as injurious as the reverse process, even though the effect may be only temporary. It is dangerous suddenly to cut off supplies from a drug addict.

"Apart from the series of experiments quoted, qualitative examination of a number of activated sludges from a variety of sources has led us to the

conclusion that iron is an essential constituent, recurring in all sludges. A casual investigation of humus sludges, which, of course, are in essence of the same species as activated sludges, has failed to find one in which iron is absent. So it would appear that iron is most desirable, if not absolutely vital, in the purification of sewage.

"Systematic determinations of bio-aeration plant sludge show that the iron varies from 6 to 20 per cent of the total dry solids. When the iron content in the sludge is stationary, or gradually increasing, the sludge is in good condition, and the reverse holds good when the iron content is decreasing. In other words, when aeration is good the iron is oxidized and tends to increase in the sludge, while with deficient aeration the iron is reduced and tends to pass out of the system. The iron in sludge probably acts as a source of oxygen supply for a limited time. The golden-brown color which iron gives to activated sludge when treating domestic sewage is largely masked by trade sewages." J. K. HOSKINS

Beautification of Sewage Treatment Works Sites

BY COL. L. E. BURNSIDE

Public Works, **63**, 9-10 and 36 (Dec., 1932)

One of the first sewage treatment works in Pennsylvania at which beautification was put into practice was the Pennypack plant in Philadelphia. The results of landscaping had a very material effect in keeping down the cost of land acquisitions and objections in the neighborhoods where additional plants were constructed in other parts of the city.

The treatment works in Sharon, Pa., were constructed about two blocks distant from one of the main thoroughfares, which is solidly built up with residences, and upon land which had served for years as a dumping ground. The construction on this location, when first proposed, was seriously objected to by the property owners in the vicinity, but within a period of two years the place was transformed by the well designed buildings, glass-covered sludge beds, lawns, tree borders, shrubbed banks and corners, to a place of beauty and pride for the city.

Suggestions for Application of Landscaping.—First in importance in landscaping about the works is the attractive appearance of structures. Second is well graded grounds, which may be level, or terraced, or a combination of the two, as best suited to the several structures, but always providing open expanses of lawns. Third is a pleasing layout of roadways needed for vehicular traffic, which should be along the boundary lines and in curves in so far as is possible, not forgetting to provide an adequate parking ground. Native trees should be planted along the property lines

and the roads. Shrubs add to the appearance, when planted about the administration building, and are desirable as screens for the parking grounds and blank corners. Shrub hedges are advisable some six to ten feet back from the outside walls of settling or Imhoff tanks when the tops of these tanks are at or near the elevation of the surrounding grounds. A screen or background along the sides and back of the grounds and around open sludge beds is also desirable. Almost any type of tree, shrub or perennial flower which is native to or will thrive in the locality is adapted for use on the grounds.

The minimum extent in landscaping the site consists of well shaped grading, plain grass lawns, and trees about the boundaries, the cost of which would be about $1/2$ per cent of the cost of the treatment works. To provide additional shrubbery, hedges and screen to conceal the unsightly areas can be accomplished at about $1\,1/2$ to 2 per cent of the cost of the works.

C. T. WRIGHT

Variations in Production of Sewage Gas

BY H. W. TAYLOR

Public Works, **63**, 34 (Dec., 1932)

To determine the maximum, average and minimum flows of sewage gas under normal conditions, a three-day test run at the plant at Rome, N. Y., was conducted in October, 1932. The figures for each day were grouped according to three distinct periods, the operating period from 8:00 A.M. to 4:30 P.M.; quiescent period from 4:30 P.M. to 2 A.M.; and the mordant period, from 2 A.M. to 8 A.M. The half-hourly readings were grouped by these periods for the three days. The averages of the results are as follows:

AVERAGE RATE OF FLOW OF GAS FROM DIGESTION TANK

	Average Percentage (100% = average of 3-day totals)		
	Maximum	Mean	Minimum
8 A.M. to 4:30 P.M.	125	95	79
4:30 P.M. to 2:00 A.M.	115	106	99
2:00 A.M. to 8:00 A.M.	109	95	81

The following table gives quantities and relations for the absolute maximum and minimum; estimates being made for quantities which, during periods of great activity, exceeded the capacity of the piping and accessories and consequently were not registered:

MAXIMUM AND MINIMUM GAS FLOWS

Description	Cubic Feet per Day	Per Cent of Average	Cubic Feet per Capita
Three-day run at Rome			
Maximum	27,000	140	1.0
Average daily total	19,370	100	0.72
Minimum	13,900	72	0.52
Peak activity at Rome in July			
Maximum	(40,000)*	(140)	1.5
Daily total	29,000	100	1.07
Minimum	(21,000)	(72)	0.77
Peak activity at Saranac Lake in July			
Maximum	(21,000)*	(140)	1.92
Daily total	15,000	100	1.37
Minimum	(10,800)	(72)	0.99

* Estimated figures in parentheses. Maximum rates caused blowing of seals during height of activity.

The author suggests that piping and accessories for handling gas should be designed for a maximum rate of flow of 2 cu. ft. per capita per day.

C. T. WRIGHT

An Activated Sludge Plant for a Small Community

BY E. H. DARLING, Consulting Engineer, Hamilton, Ont.

Canadian Engineer, **63**, 19 (November 15, 1932)

This article emphasizes the low cost, efficiency and automatic control of a small plant which was built for suburban area near Welland, Ont., during the winter of 1931–32.

The plant has a capacity of 100,000 gallons in 16 hours. It provides four hours aeration and two hours sludge settling capacity. There are likewise bar gratings, a sludge digestion tank, sewage pumps and blower equipment and sludge drying beds.

The sewage pumps each operate at the rate of 100 g. p. m. They are in duplicate and are controlled by mercoid pressure switches. The aeration tank is a two pass tank, each pass being apparently (by scaled plan) about 9 feet wide and 7 feet maximum water depth. The tank is covered except over the diffuser plates. The blower equipment consists of one air-cooled rotary positive blower of 200 c. f. m. capacity at four pound pressure. The blower is set on a cork base and is provided with a muffler.

The sludge setting tank is a square tank of the Dortmund type about 18 feet square and 16 feet water depth. This tank is covered.

Sludge from the sludge settling tank flows (continuously and automatically) part to the sludge digestion tank and part to a sludge aeration channel which in turn feeds the activated sludge to the influent sewage

ahead of the pumps. The digestion tank is about 18 feet square, with about 7 feet side water depth and is covered. Supernatant liquor is discharged to the influent sewer. Sludge, when digested, is drawn off to (two) open drying beds (1250 sq. ft.). Drainage from the sludge drying beds also goes to the inlet sewer.

Operation of the several tanks and including the addition of activated sludge to the influent sewage is responsive to the variation in the water level over outlet weirs, and is thus in tune with the pumping of the sewage. The removal of settled sludge and the overflow of supernatant is continuous.

The plant is a compact one. The aeration, sludge settling and sludge digestion tanks are arranged in line with one pair of walls common to all three tanks. Most of the superficial area is decked over and buildings are restricted to a small pump house. The plant is visited by an operator twice daily. The cost of construction with relief labor was about $16,000.00.

FRANK TOLLES

The Lime-Chlorine Process of Sewage Treatment at Baltimore

BY C. E. KEEFER AND G. K. ARMELING

Water Works and Sewerage, **79**, 168–70 (May, 1932)

Due to the discharge of nitrified effluent into the Back River, considerable algae growth formed. Laboratory experiments were made using chlorine alone and chlorine and lime. The latter treatment was the more efficacious as well as cheaper. The chemicals were added direct to the final effluent before its discharge into the river.

The sewage works is a sedimentation-trickling filter plant with a flow (1931) of 60.97 m. g. d. The settled sewage is treated on 30 acres of trickling filters and again settled in two humus tanks.

Laboratory experiments showed that an average of 3.70 p. p. m. of chlorine were needed to supply the initial chlorine demand if chlorine water was used, while only 1.18 p. p. m. were necessary if the chlorine was in the form of hypochlorite (chlorine water and lime mixed in the proper proportions). In order to have a residual chlorine content of 0.5 p. p. m., 6.19 p. p. m. of chlorine was needed when using chlorine water and only 3.69 p. p. m. when hypochlorite solution was used, or a saving of 40.4 per cent. With chlorine at 2 cents and hydrated lime at $^1/_2$ cent a pound each 1000 pounds of chlorine used would cost $20.00 whereas the treatment with chlorine (596 lb.) and lime (745 lb.) the cost would be $15.65 or a saving of 21 per cent.

Each lime-feed machine operates automatically and feeds the proper quantity of lime mixed with water through a 4-inch cast iron pipe to the sewage effluent channel. Chlorine dissolved in water also flows into this pipe line. The ratio of chlorine to hydrated lime necessary to form alkaline calcium hypochlorite is approximately 1 to 1.25. In order to be sure that there is an excess of lime, "flash" tests are made (a pink "flash" is obtained when phenolphthalein indicator is dropped into a sample of chlorinated lime, but the color disappears within a few seconds).

Five- and 20-day oxygen demands were determined on both the chlorinated and unchlorinated effluent, using the Sierp method. The average 5-day B. O. D. of the unchlorinated effluent was 48 p. p. m. and of the chlorinated 32 p. p. m. or 33 per cent reduction. With the 20-day demand the results were 116 p. p. m. and 100 p. p. m., respectively, in the untreated and treated, or a reduction of 14 per cent.

Experiments were also made in the laboratory by treating the sewage with cupric chloride, to see what effect small quantities of copper had upon algae. When using 0.5 p. p. m. of cupric chloride there was no indication of inhibition of algae growth. H. GLADYS SWOPE

Sodium Nitrate Used to Control Nuisance

BY WILLIAM T. CARPENTER

Water Works and Sewerage, **79**, 175-6 (May, 1932)

Coney Island Creek, which originally formed a connection between Sheepshead Bay and New York Bay, is now almost landlocked, and less than a mile from its mouth it is too shallow for navigation except by rowboat. Six million gallons of sewage besides some wastes from a gas plant pour into this creek daily. This mass of filth oscillates up and down stream with the changing tide and is only slowly forced out into Gravesend Bay.

Hydrogen sulphide is noticeable throughout the year and became so obnoxious in the warm dry summer of 1930 that it was necessary to alleviate the situation.

In August, 1930, ten tons of sodium nitrate and several tons of chlorinated lime were purchased. One ton of the chlorinated lime was strewn upon the surface of the water near the mouth of the creek. Sodium nitrate was added in solution form and 1000 lb. was applied at each flood tide.

On July 14 and 15 the average dissolved hydrogen sulphide content at the lower stretch of the creek was 8.4 and 9.5 p. p. m., respectively, and on August 6 it was 16.5 p. p. m. The chlorine treatment reduced this to

12.7 p. p. m. within an hour and on the 14 the amount was 6.5 p. p. m. The treatment was stopped on August 13 and the hydrogen sulphide content rose to 9.3 p. p. m. on August 18.

On this latter date treatment was started at the upper reaches of the creek where the condition was less severe. The hypochlorite was made into a cream and 1300 lb. were added and also 1000 lb. of sodium nitrate. The effect was not immediate but by the 25th the creek had become milky white and was odorless. The hydrogen sulphide content on August 18th was 7.3 p. p. m., on the 20th, 8.3 and by the 27th had reached a minimum of 3.2 p. p. m. H. GLADYS SWOPE

The Treatment of Milk Products Waste

Report No. 4

BY E. F. ELDRIDGE

Michigan Engineering Experiment Station, *Bulletin*, No. **48** (November, 1932)

This report deals with the treatment of milk products waste by the activated-sludge process. Previous reports from this station have dealt with the treatment of these wastes by chemical precipitation and biological filtration.

Plant.—The experimental plant consisted of an aeration tank eight feet in diameter and six feet water depth, equipped with a Simplex aerator, followed by a rectangular settling tank of 600 gallons capacity, and centrifugal pumps for the influent and sludge return. The Simplex aerator was a specially made unit, much smaller than the standard units. It was driven by a $^1/_2$-hp. motor through a speed reduction gear.

The plant was erected at the college dairy to study the treatment of milk wastes alone. Before starting the process, a special run was made to test the ability of the Simplex unit to aerate the sewage. The aeration tank was filled with a strong milk waste of 2000 p. p. m. B. O. D. and the aerator started. Samples were taken at frequent intervals for dissolved oxygen determinations. A plot was made of the results of this run, D. O. against time of aeration, and a curve obtained from previous tests using aeration by compressed air is given for comparison.

The results were in favor of the Simplex unit which raised the dissolved oxygen content of the tank to a maximum of 7.2 p. p. m. two hours from the start, with a gradual drop to 0.8 p. p. m. after seventeen hours. Figures for the compressed aeration were 5.0 p. p. m. D. O. in one hour and a drop to zero D. O. in about four and one-half hours. The quantity of air used in the diffused air test is not stated.

Treatment of Milk Products Waste Alone

Sewage was pumped to the plant during the working hours of the dairy, which were between 8 A.M. and 4 P.M. The aerator was operated over the entire 24 hours, the sludge in the settling tank being pumped to the aeration tank after the close of a day's run. As a means of expressing the aeration period, the capacity of the aeration tank was divided by the gallons of sewage pumped per hour. This expression was called the "hours of aeration with load applied." Runs were made with this figure at 19, 9.5, 8.0 and 5.5 hours. The daily average B. O. D. of the plant influent varied between 340 and 1200 p. p. m.

With the 19-hour period it was impossible to build up sufficient activated sludge as it was apparently oxidized by the long aeration period. The 9.5-hour period gave good results with an average reduction of B. O. D. of 92 per cent. The sludge was light as was to be expected from the character of the wastes, but it was heavy enough for satisfactory operation. Very little sludge was wasted as the excess sludge was apparently oxidized.

When the rate was increased to 5.5 hours of aeration the sludge began to bulk and much of it was lost with the effluent. Other characteristics of this under-aerated condition were: (1) a marked increase in the fat content of the sludge and of the plant effluent, (2) a scum of fat on the final tank, (3) the presence of lactose in the aeration tanks and in the plant effluent and (4) a drop in the pH of the aeration tank contents during the day from 7.8 in the morning to 6.7 in the afternoon. The B. O. D. removal was fair, however, figures of 77 and 71 per cent being given.

The results from the run with the 8.0 period were slightly better than those obtained with the 9.5 hour period. A table is given showing the first cost and operating costs for different sized plants to treat milk wastes, using Simplex aerators.

Combined Domestic Sewage and Milk Waste

The experimental plant was moved to Mason and tests were made on a sewage of about equal parts of domestic sewage and milk wastes. Before reaching the aeration tank the wastes passed through a settling tank. The strength of the milk wastes varied considerably depending on the product being manufactured. The B. O. D. of the combined sewage during the day was between 400 and 600 p. p. m. with a 24-hour average of between 120 and 326 p. p. m. Sewage was pumped to the plant over the entire 24 hours at rates to give "rates of aeration with load applied" of 19, 9.5, 8.0 and 5.5 hours.

The 19-hour period gave poor results as the sludge was broken up by the too long aeration period. The reduction of B. O. D. with the 9.5-, 8.0- and 5.5-hour periods was between 85 and 93 per cent, and the fat

content of the wastes was reduced from 40 p. p. m. to 8 p. p. m. It was impossible to get a dense sludge with this type of wastes. The average ash content of the sludge was 22 per cent showing it to be largely organic in nature. There was a relation between the fat content of this sludge and its settling ability, a rapidly settling sludge having a low fat content. Furthermore, when sludge was settled in a cylinder the lower layers of sludge contained much less fat than the top layer. The addition of lime and/or ferric chloride corrected the bulking of the sludge to some extent but the effect was only temporary. RALPH J. BUSHEE

Ohio Conference on Sewage Treatment, Fifth Annual Report, October, 1931

Operation of the Akron Sewage Treatment Works

BY T. C. SCHAETZLE

Engineer-Chemist in Charge

The new sewage works designed for an average flow of 33 m. g. d., consists of racks, 2 detritus tanks (Dorr mechanism), 2 fine screens, 2 Venturi meters, 24 Imhoff tanks, 14 acres of trickling filters, 12 humus tanks and $3^3/_4$ acres of sludge drying beds.

At first difficulty was encountered with the first detritus tank as it received the bulk of the rags and heavier material. New scrapers were put in with the blades spaced $2^1/_2$ feet apart and extending entirely back of the spider arms. There is no brass squeegee attached to the plow as the raking device is set so the scrapers ride about one inch above the concrete surface, thus forming a cushion of sand into which the rags are pushed as they pass under the front beveled edge of the scraper blade. This change has remedied the difficulty.

The Dorr fine screens clogged and for a time this was relieved by cleaning with kerosene each day. Now, a screen is taken out of service for a week and cleaned with a broom and water.

Scum formation in the flow chambers of the Imhoff tanks has been minimized by keeping the sludge 10 feet below the slot. Foaming has been controlled by the use of plenty of water from an auxiliary creek supply.

The plant was originally designed to return the humus sludge to the Imhoff tanks but this upset the equilibrium of the tanks so much that the humus sludge was finally run onto lagoons and sludge drying beds.

Pooling of the trickling filters occurred to such an extent in 1930 that the filters were shut down from Nov., 1930, to May, 1931. To prevent pooling H. T. H., hypochlorite of lime and harrowing were tried. Harrowing produced good results at low cost.

The difficulty in the entire plant was due to an excessive solids load, caused in the main by the rubber reclaiming plants. Coöperation is now being secured from these people.

Sludge Digestion—A Theoretical Discussion

BY ROBERT A. ALLTON

Sewage Disposal Engineer, Columbus

The formula presented herewith is an attempt to predict the capacity of sludge digestion chambers.

$$R = F + N + D\left(\frac{100 - p}{100}\right)^t$$

where

t = the digestion period in days,
F = the fixed solids in one pound of fresh sludge solids, in pounds,
N = the non-digestible volatile solids in one pound of fresh sludge solids, in pounds,
D = the digestible volatile solids in one pound of fresh sludge solids, in pounds,
P = the per cent digestion in one day,
R = the residue from the digestion of $(F + N + D)$ pounds of fresh sludge solids after a digestion period of t days, in pounds.

The assumptions made are as follows:

1. The sludge digestion tank has passed through the ripening stage and is functioning normally.
2. The raw solids added to the digestion tank can be divided into fixed solids and volatile solids.
3. The volatile solids can be divided into digestible volatile solids and non-digestible volatile solids.
4. All digestion takes place in the digestible volatile solids.
5. The digestion of the digestible volatile solids follows the monomolecular reaction law.
6. The speed of digestion is a function of the temperature of the sludge.

Conclusions:

1. The determination of volatile solids, as determined by ignition, does not give a true picture of the proportion of sludge solids which can be destroyed by digestion and a new determination which will give directly and easily the digestible solids is needed.
2. The two curves (digestion period in days against residue from digestion in pounds; and digestion period in days against pounds of sludge solids) used together give all the data necessary to design a digestion tank.

If a digested sludge contains 50 per cent fixed solids and 50 per cent volatile solids, the digestion period and weight of solids can be determined from the curves. It is then only necessary to convert the dry solids to the equivalent volume of sludge of a given moisture content to obtain the net volume of the digestion tanks.

Discussion

BY FRANK WOODBURY JONES

With George B. Gascoigne, Cleveland

Mr. Jones objects to the last sentence above, in that the moisture content can never be predicted with certainty. Mr. Jones makes the assumption that all of the digestion takes place in the volatile matter, and sets up the following equation:

$$D = \frac{F - P}{F}$$

where

D = percentage reduction in dry solids,
F = fixed solids in digested sludge in per cent.
P = fixed solids in fresh sludge in per cent.

The Elyria Sewage Treatment Works

BY JAMES R. COLLIER

Superintendent and Chemist

The treatment plant consists of bar screens, grit chambers, two-story tanks of the Imhoff type, aeration tanks, sludge-settling tanks, separate sludge-digestion tanks and sludge-drying beds. The plant was designed to serve a population of 36,000.

Two primary settling tanks of the Imhoff type are provided: (1) to equalize the sewage flow and the concentration of the sewage; (2) to lighten the burden on the oxidation treatment by collection of the settleable solids. (3) partially to condition and concentrate the settling solids; and (4) to provide sedimentation for sewage flows in excess of the normal dry weather flow. Each tank has six gas vents covered with gas collection domes set in water seals.

The aeration tanks are of the spiral flow type. The aeration period for 3.6 m. g. d. and 20 per cent return sludge is 4 hours.

The separate sludge digestion tanks are maintained at a temperature of 78° F. Both tanks are equipped with floating covers with provisions for gas collection. Supernatant liquor may be drawn off at either of two elevations and can be discharged onto the sludge drying beds, pumped to the sewage as it enters the Imhoff tanks or pumped to the sludge compartments of the Imhoff tanks. There is no provision for gas storage.

The volatile content of the fresh solids deposited in the Imhoff tank varies from 65 to 85 per cent, averaging about 72 per cent. In the Imhoff tanks volatile solids of the sludge are reduced to from 55 to 65 per cent. Sludge from the digesters is discharged upon the drying beds with an average volatile matter content of 46 per cent.

From January through September, 1931, a total of 3,331,800 cu. ft. of gas was produced of which 9.5 per cent was generated in the primary tanks. Forty-seven and one-half per cent of the total amount was used for sludge heating. Weekly gas analyses during this period averaged as follows:

	Methane	Carbon Dioxide	B. t. u.
Primary tank	86.8	12.1	928
Digestion tank	69.8	30.1	744

ANALYSES OF SEWAGE AND EFFLUENT FROM JANUARY TO SEPTEMBER, 1931

	Parts Per Million							
	Solids			Nitrogen				Oxygen Consumed
	Total	Dissolved	Suspended	Total Organic	Free NH_3	Nitrates	5-Day B. O. D.	(hot)
Raw	761	540	221	10.8	17.7	0.39	211	65.2
Settled Effluent	629	532	98	7.6	18.0	0.35	129	44.7
Final Effluent	522	504	18	3.3	4.4	12.1	9.5	15.8

Trickling Filter Loadings

BY B. F. HATCH

Asst. Eng., Ohio Dept. of Health, Columbus

The writer tabulates data and discusses a "yardstick" to determine trickling filter loadings. He states that the filter load may be formulated in pounds of oxygen required by the applied sewage per 1000 cubic feet of filtering material. Such a yardstick is calibrated in terms of the actual ability of a trickling filter to supply the oxygen required to modify the organic matter contained in the applied waste to a more stable form. The expression takes into consideration both the gallonage and concentration of the applied waste.

Round Table Discussions

These discussions covered operation details of grit chambers, trickling filters, sewage treatment plant odors, chlorination, gas production and the suspended solids determination.

Report of Investigation of the Calcar Process of Treatment of Municipal Sewage at Circleville

BY F. H. WARING

Chief Engineer, Ohio Department of Health, Columbus

The Calcar process of sewage treatment is essentially a chemical precipitation process. The precipitant is a mixture of marl, hydrated lime and ferrous sulphate.

The city of Circleville is located in the valley of the Scioto River. Circleville has a population of about 7500 people. The sewage which enters the

treatment plant is almost entirely domestic with the exception of some dye wastes from a broom-corn factory. The wastes from the other industries (straw paper mill, canneries and creamery) discharge directly into the Scioto River. The domestic sewage has a five-day oxygen demand of 340 pounds whereas the industrial wastes have a demand of 18,700 pounds.

In dry weather the stream flow at Circleville has been as low as 158 second feet, and assuming an initial D. O. of 7.5 p. p. m. depleted to 3.0 p. p. m., it would leave only 3830 pounds of oxygen available. The domestic and industrial wastes should therefore be given from 70–90 per cent treatment.

The plant consists of a pumping station, chemical dosing devices, a plain sedimentation tank and a cascade aerator. In the pumping station is a gate controlled diversion chamber, a coarse bar screen, a pumping sump, 2 float-controlled electrically operated centrifugal pumps, 2 solution tanks with motor driven agitators for feeding chemicals, a motor driven centrifugal sludge pump and a laboratory. The sedimentation tank is divided into two compartments: the main compartment being provided with an underflow inlet baffle, an overflow outlet baffle and a shallow trapezoidal sludge pit with one valve controlled sludge outlet pipe; the secondary compartment is an upward flow, shallow sand and gravel filter, resting on a false bottom with a shallow trapezoidal sludge pit beneath, served by one valve controlled sludge withdrawal pipe. The effluent from the secondary compartment spills over an apron onto a cascade aerator and then into the Scioto River.

The chemicals are added as follows: The marl and lime mixture is discharged into the raw sewage in the diversion chamber ahead of the screens and the ferrous sulphate solution is added in the screen chamber.

The cascade aerator is merely a sloping ramp $20^1/_2$ ft. long with side curbs. The aerator has a total drop of about $4^1/_2$ feet.

To test the efficiency of the plant, detailed analytical tests were made on the raw sewage and effluent. Both catch samples and composited samples were collected, the final effluent being collected two hours after the raw sewage sample as it took approximately two hours for the sewage to flow through the plant

AVERAGE ANALYSES OF COMPOSITE SAMPLES

	May, 1931		June, 1931	
	Raw	Effluent	Raw	Effluent
	(Parts Per Million)			
Total Solids	860	528	940	561
Suspended Solids	210	67	281	59
Dissolved Oxygen	0.2	0.5	0	0
5-Day B. O. D.	219	62	271	87
Total Nitrogen	43	34	44	34
Organic Nitrogen	17	10	19	9

Ammonia Nitrogen	26	24	25	25
Nitrites	0	0.2	0	0
Total Alkalinity	388	230	411	240
pH	7.2	9.3	7.3	9.0

AVERAGE AMOUNTS OF CHEMICALS APPLIED

	Grains Per Gallon	
	May	June
Marl	25.7	27.3
Lime (CaO)	15.1	12.5
Ferrous Sulphate	1.7	2.2

There were some interesting observations made regarding the results obtained when making determinations on catch samples and on composite samples. The lime treatment caused a softening reaction in the final effluent with resulting deposition of sludge during the interval between collection of samples and their examination. A catch sample of effluent which was estimated to contain 5 p. p. m. suspended solids was found to contain 49 p. p. m. 18 hours later. The D. O. in a catch sample was 5.2 p. p. m. and 18 hours later it had no dissolved oxygen.

In order to estimate the amount of colloidal matter removed from the crude sewage by the Calcar process the following tests were made: Portions of composite samples of crude sewage were centrifuged for 10 minutes at 2000 r. p. m. and B. O. D. run on these samples. The average of nine tests showed that the 5-day B. O. D. on the crude sewage, centrifuged sewage and effluent were, respectively, 228, 96 and 65 p. p. m. From this it was concluded that colloidal matter having an average 5-day B. O. D. of 31 p. p. m. was removed from the crude sewage by the Calcar process.

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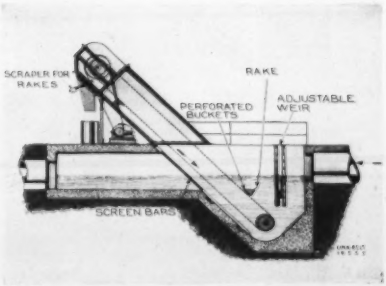

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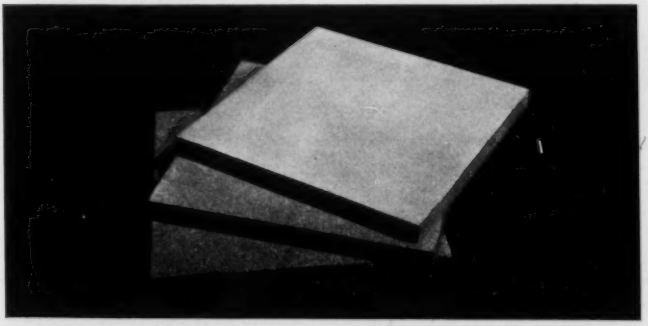
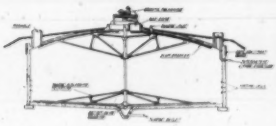


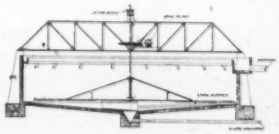
Sewage Treatment Equipment

Digesters



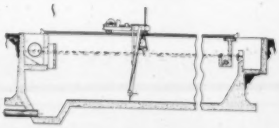
The Hardinge Dome Roof Digester, which uses the Hewett method of prestressing the reinforced steel, is self supporting, and further serves to support the mechanism, earth backfill and housing. The method of reinforcing utilizes the full value of the steel, economizes in the amount of material used, and places the concrete in compression. No cracks can form and gas leakage is eliminated. The digester is attractive in appearance and is equipped with sludge scraping and scum breaking mechanism.

Spiral Clarifiers



The spiral clarifier mechanisms are used in circular and square tanks. Where the square tank is used, the bottoms are rounded out by filling in the corners with sloping fills. An important feature of this Clarifier is that it completely cleans the tank floor, and removes the settled solids in a shorter period of time than is possible with other types of revolving mechanisms with a minimum of mechanical disturbance.

Rectangular Clarifiers



The Rectangular Clarifier consists of a traveling bridge crane, spanning a rectangular tank and carrying the sludge scraper and skimmer. This mechanism cleans the entire floor each time it passes down the tank. The sludge hopper may be located at either end or in the center. The scum skimmer keeps the surface clean. The Clarifier is automatic in operation and cannot be damaged if foreign materials enter the tank.

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